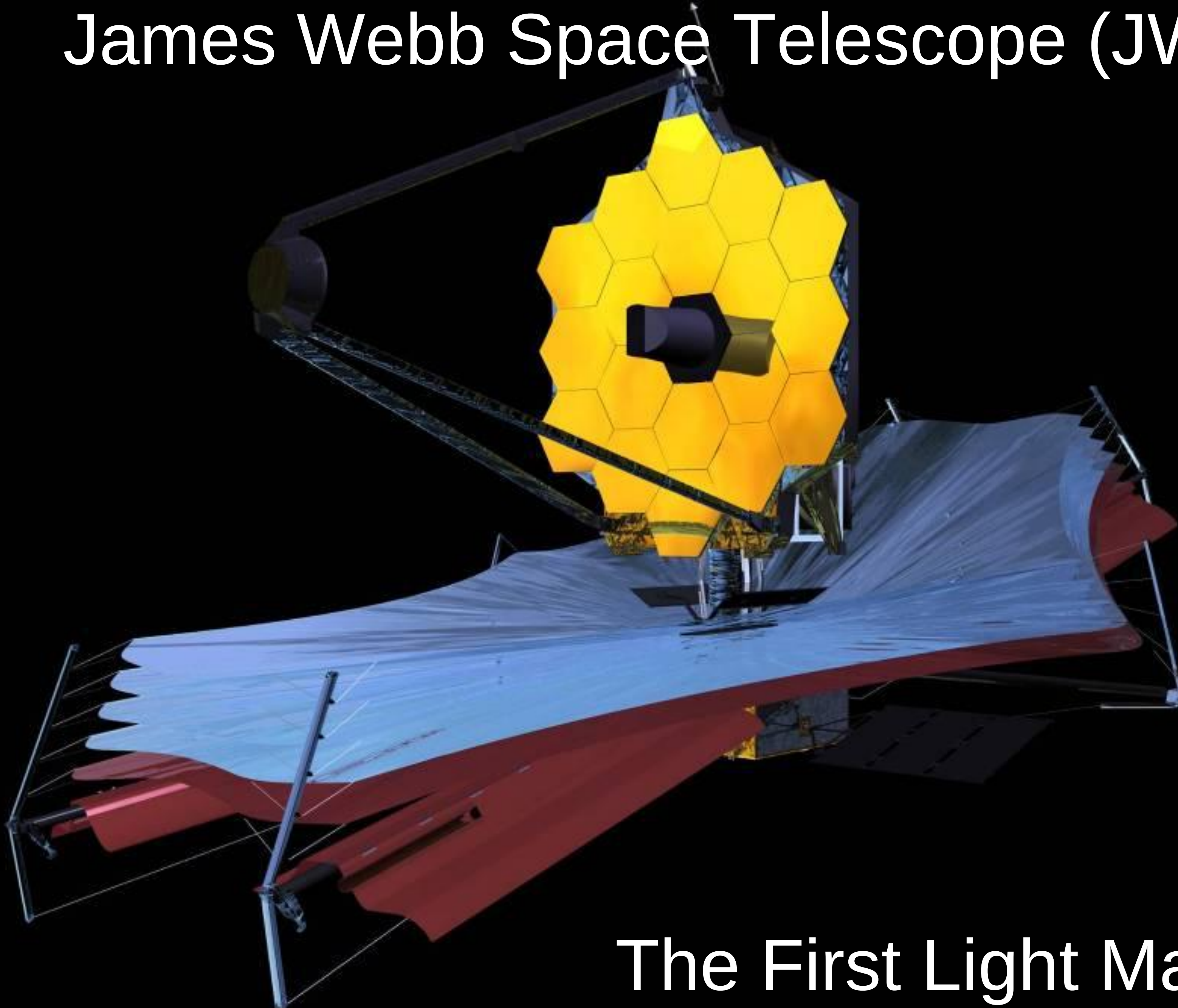
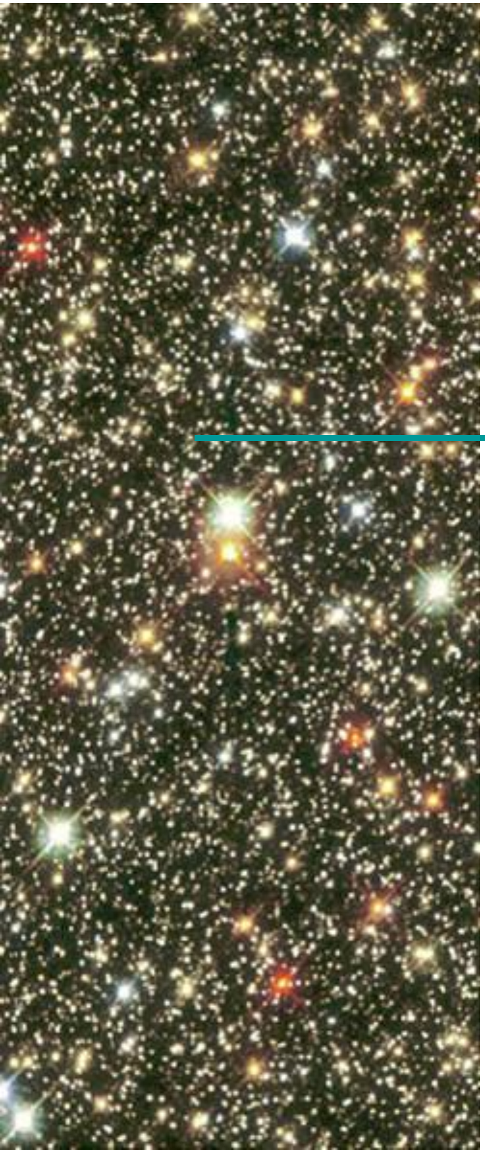
James Webb Space Telescope (JWST)

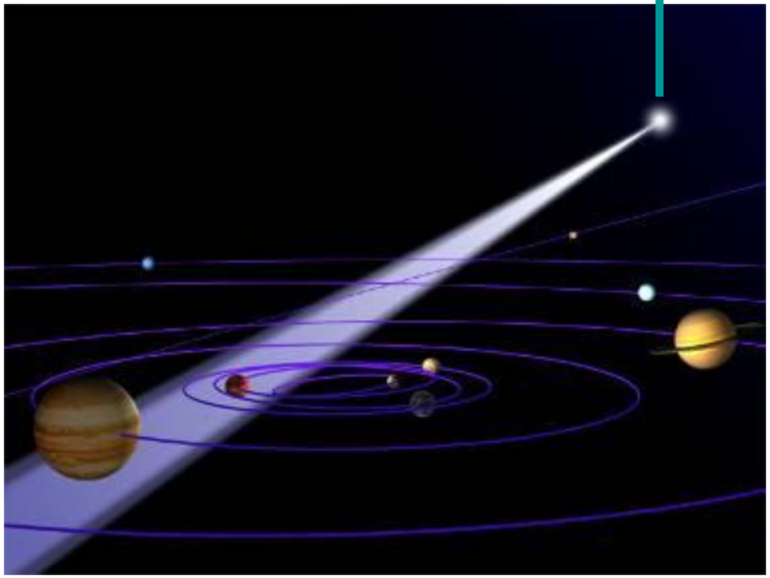


The First Light Machine

Origins Theme's ***Two*** Fundamental Questions

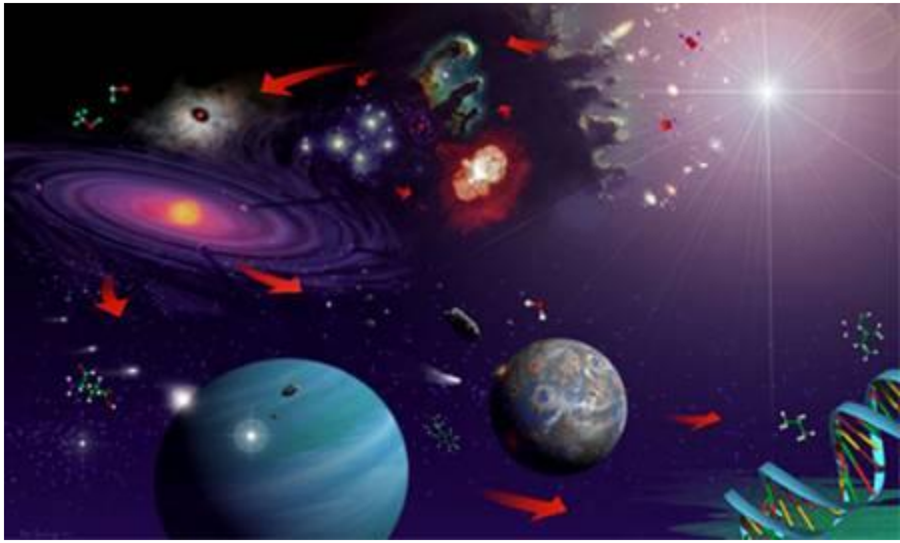


- How Did We Get Here?
- Are We Alone?



How Did We Get Here?

Trace Our Cosmic Roots



Formation of galaxies

Formation of stars

Formation of heavy elements

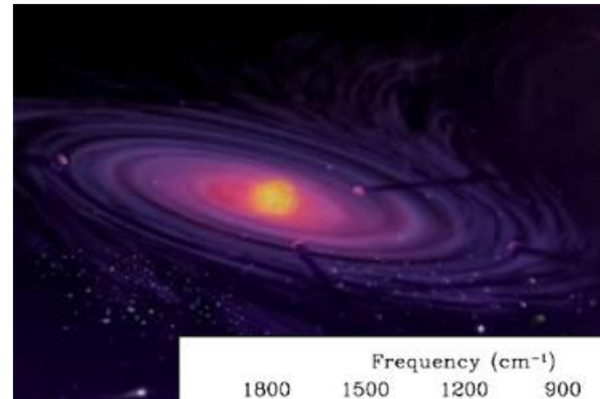
Formation of planetary systems

Formation of life on the early Earth

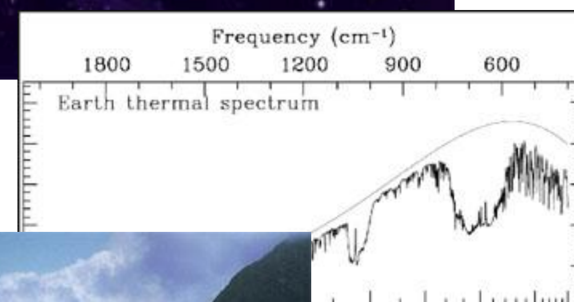
Are We Alone?

Search for life outside the solar system

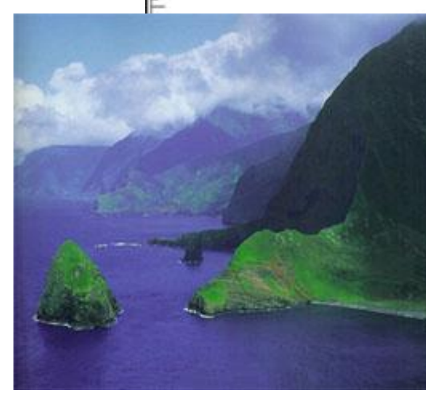
Search for other planetary systems



Search for habitable planets



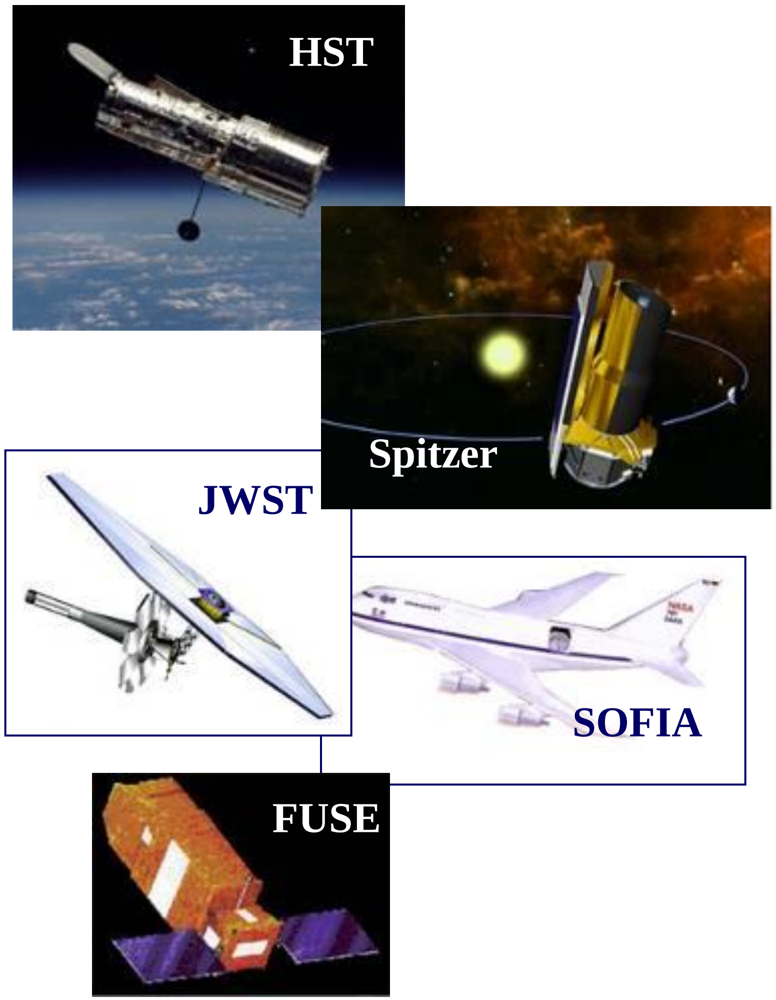
Identify remotely detectable bio-signatures



Search for “smoking guns” indicating biological activities

Missions Supporting the Origins Goals

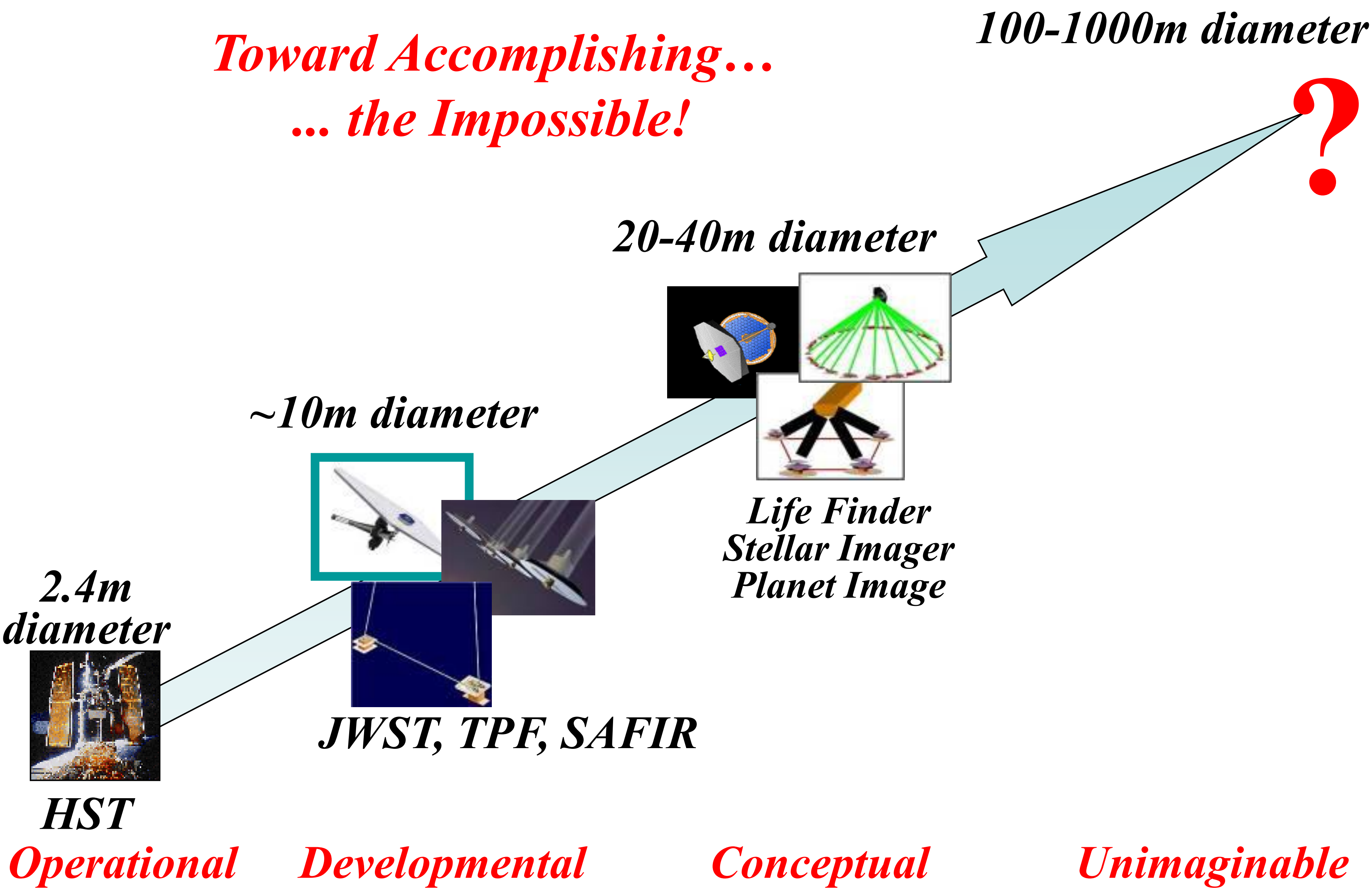
How Did We Get Here?



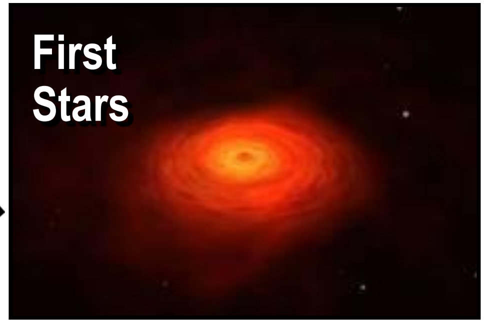
Cross Feed Science & Technology

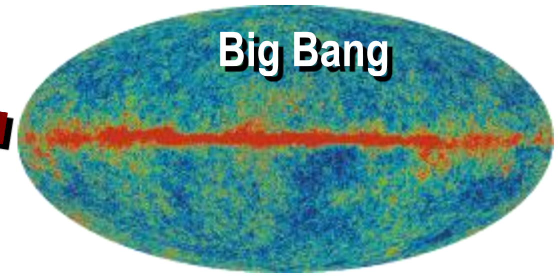
Are We Alone?

A Vision for Large Telescopes & Collectors



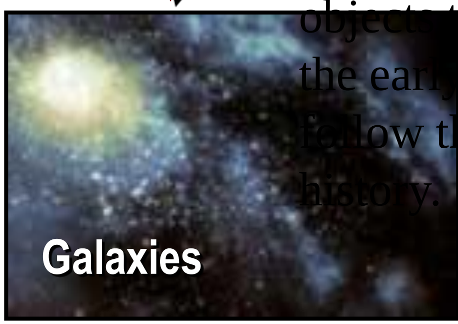
JWST Science Themes

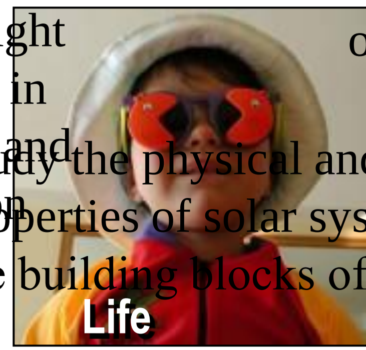




Observe the birth and early development of stars and the formation of planets.

Identify the first bright objects that formed in the early Universe, and follow the ionization history.





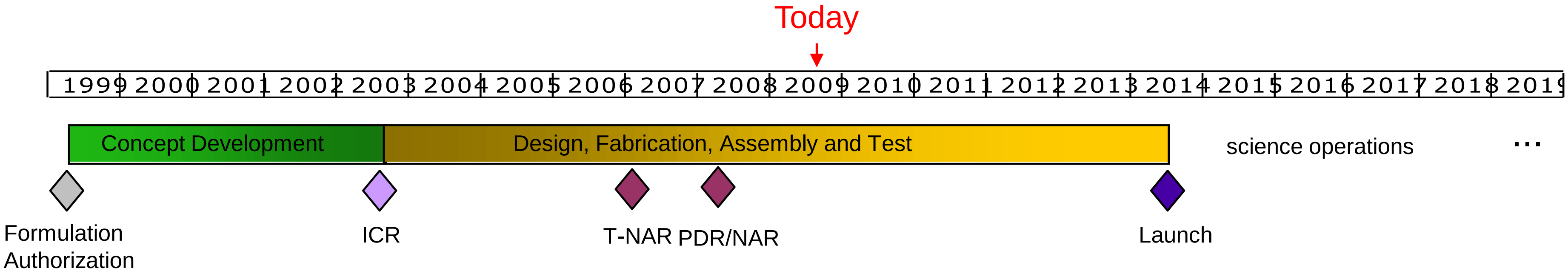
Study the physical and chemical properties of solar systems for the building blocks of ….

Determine how galaxies form

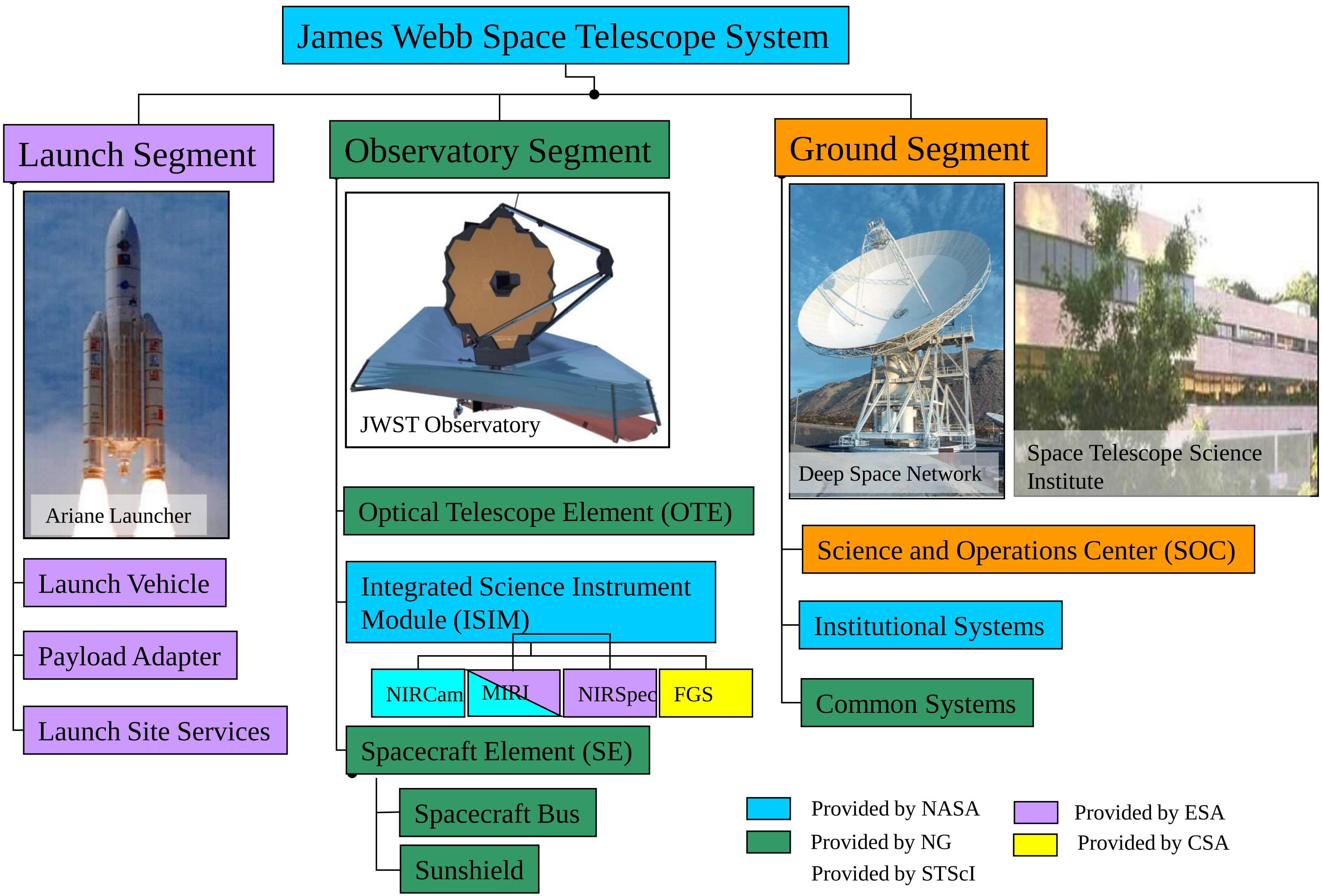
Determine how galaxies and dark matter, including gas, stars, metals, overall morphology and active nuclei evolved to the present day.

JWST Summary

- **Mission Objective**
  - Study origin & evolution of galaxies, stars & planetary systems
  - Optimized for near infrared wavelength (0.6 –28 μm)
  - 5 year Mission Life (10 year Goal)
- **Organization**
  - Mission Lead: Goddard Space Flight Center
  - International collaboration with ESA & CSA
  - Prime Contractor: Northrop Grumman Space Technology
  - Instruments:
    - Near Infrared Camera (NIRCam) – Univ. of Arizona
    - Near Infrared Spectrometer (NIRSpec) – ESA
    - Mid-Infrared Instrument (MIRI) – JPL/ESA
    - Fine Guidance Sensor (FGS) – CSA
  - Operations: Space Telescope Science Institute



The JWST system consists of three segments



The observatory segment consists of three main elements

Optical Telescope Element (OTE)

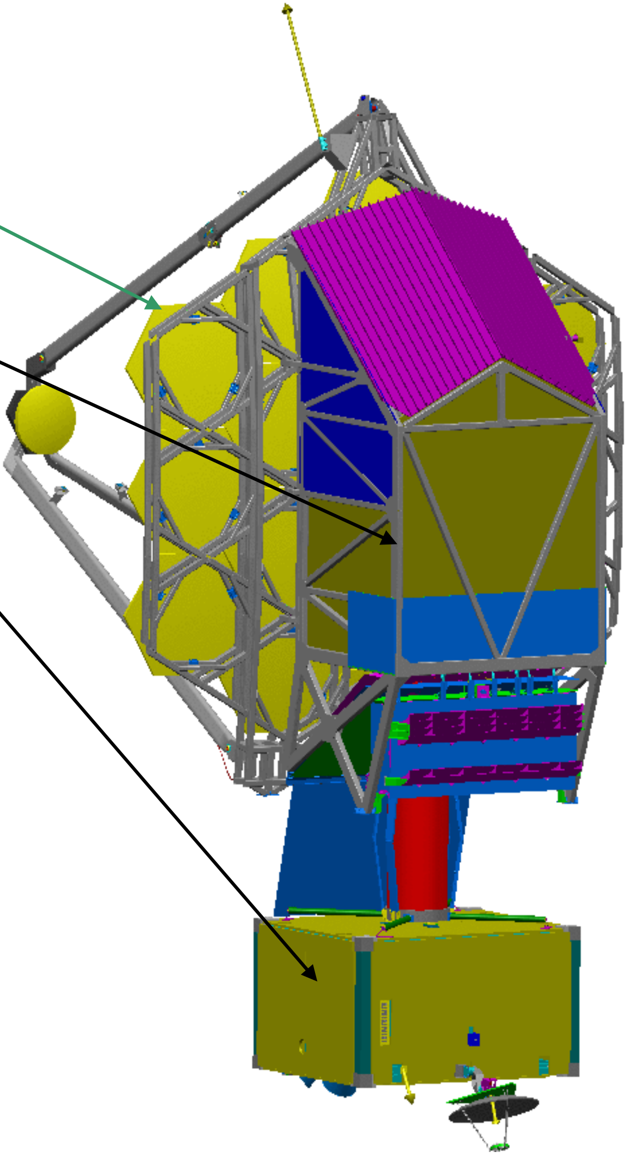
- Collects star light from distant objects

Integrated Science Instrument Module (ISIM)

- Decodes physics information from star light and converts to digital data

Spacecraft

- Attitude control, telecom, power & other support systems



JWST Requirements

Optical Telescope Element

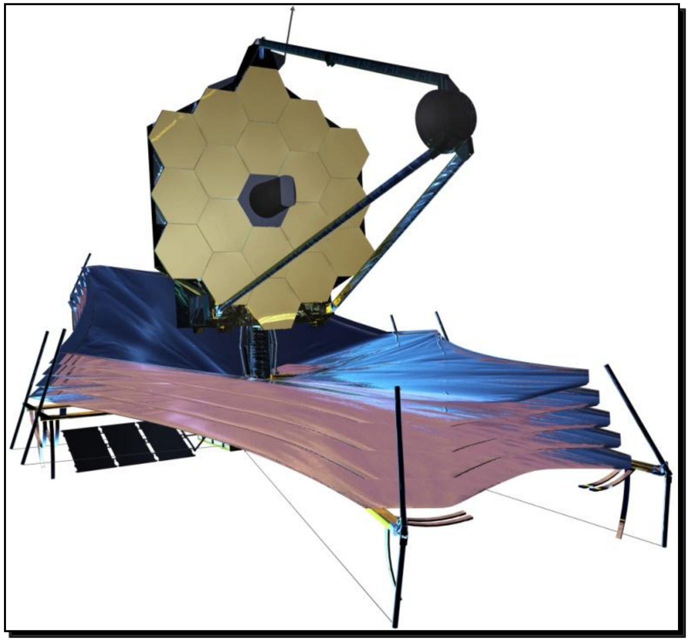
- 25 sq meter Collecting Area
- 2 micrometer Diffraction Limit
- < 50K (~35K) Operating Temp

Primary Mirror

- 6.6 meter diameter (tip to tip)
- < 25 kg/m^2 Areal Density
- < \$4 M/m^2 Areal Cost
- 18 Hex Segments in 2 Rings
- Drop Leaf Wing Deployment

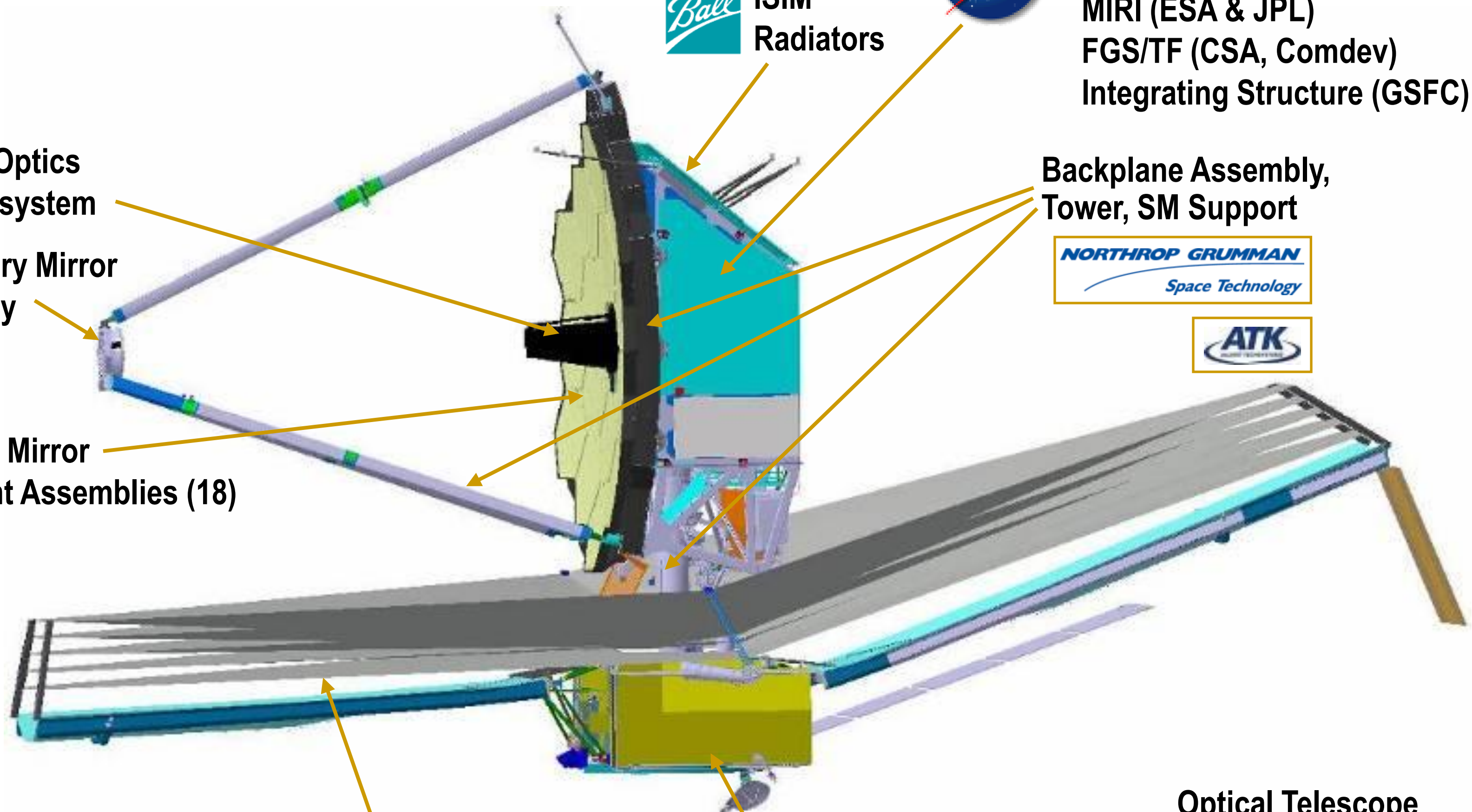
Segments

- 1.315 meter Flat to Flat Diameter
- < 20 nm rms Surface Figure Error

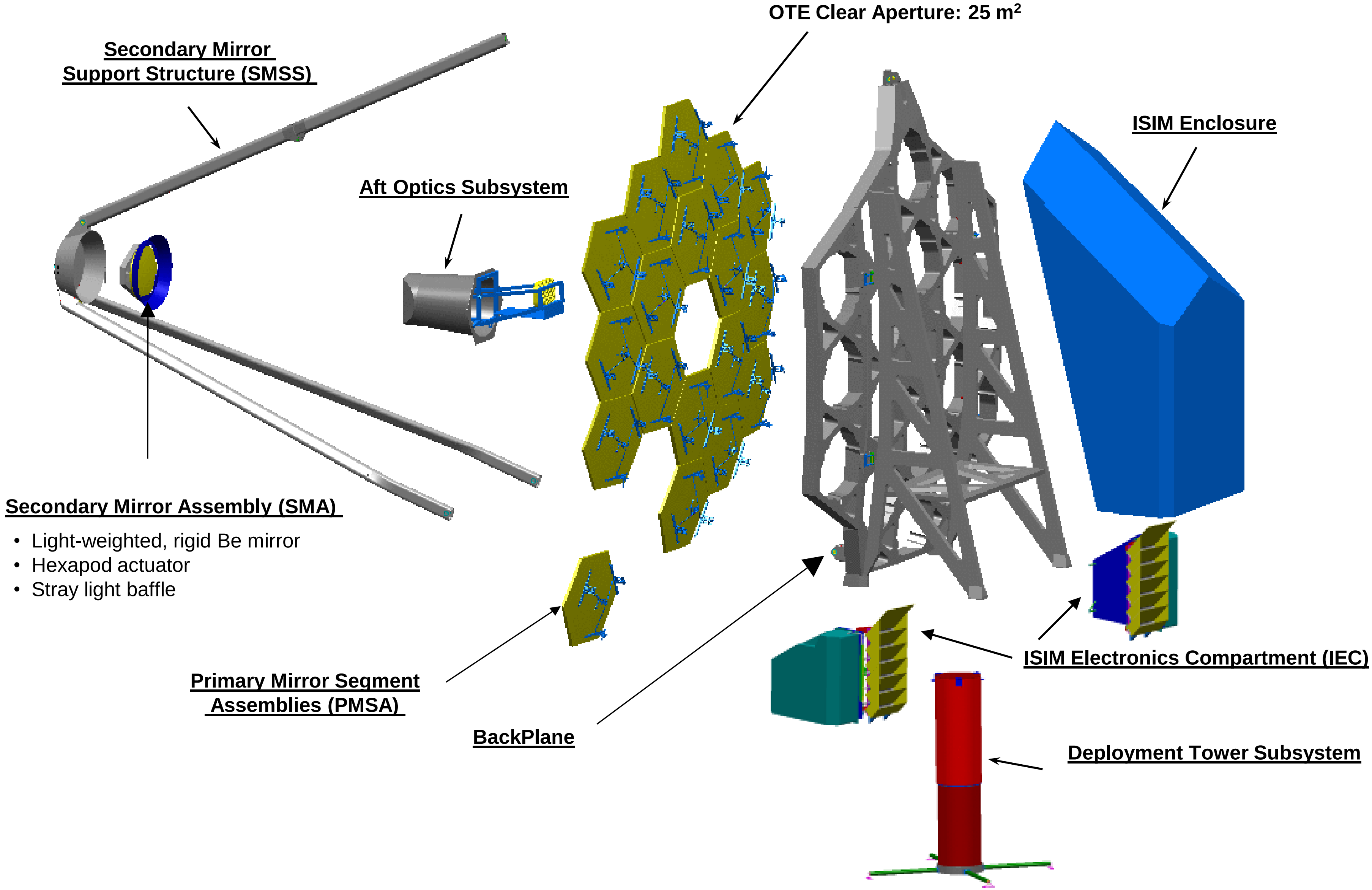


Low (0-5 cycles/aper)	4 nm rms
CSF (5-35 cycles/aper)	18 nm rms
Mid (35-65K cycles/aper)	7 nm rms
Micro-roughness	<4 nm rms

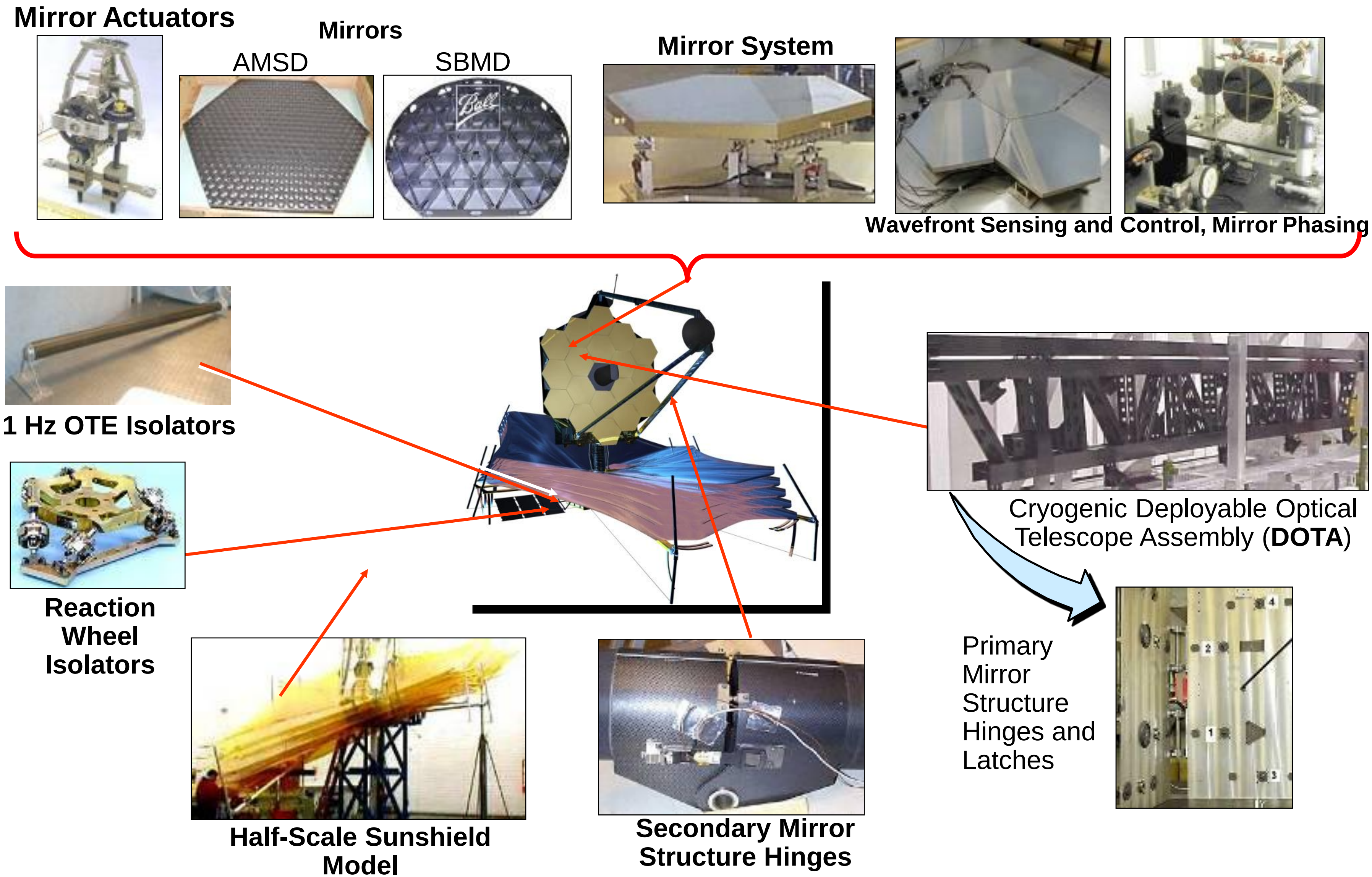
JWST Observatory Elements



OTE Architecture Concept

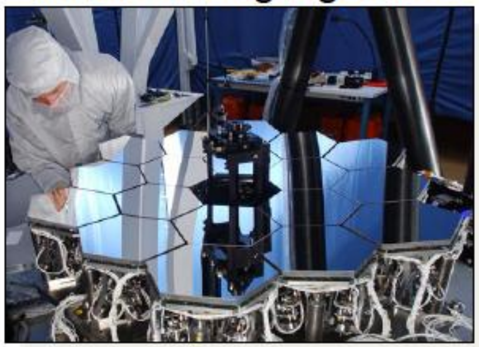


Investments Have Reduced Risk

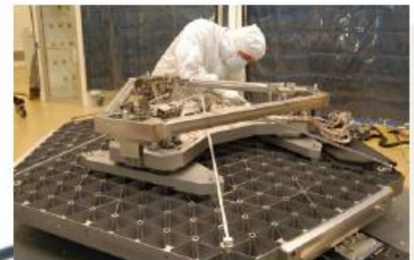


JWST Technology Demonstrations for T-NAR

Mirror Phasing Algorithms

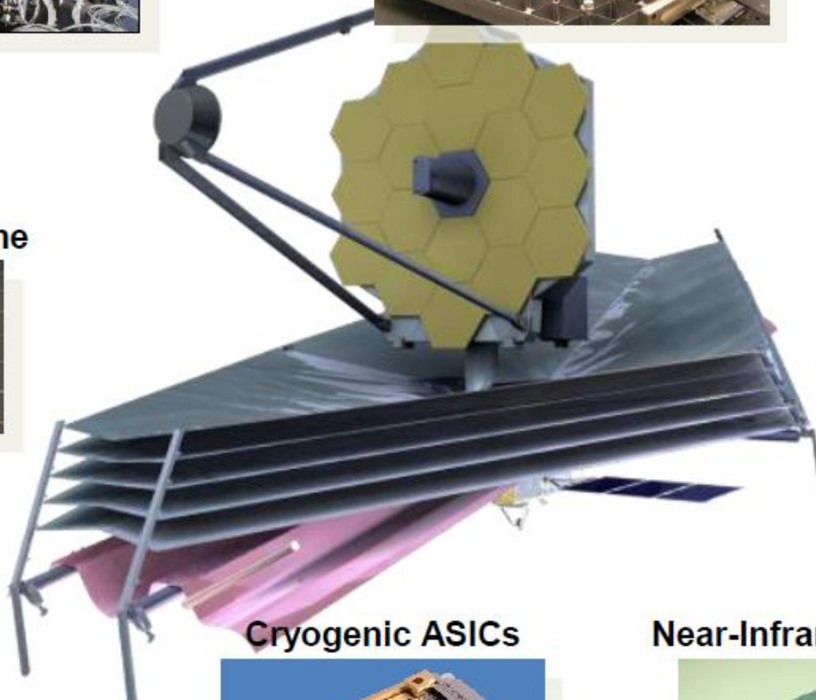


Beryllium Primary Mirror Segment

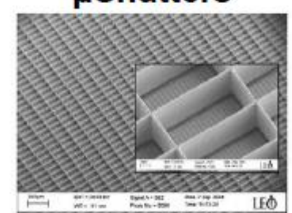


Backplane

Sunshield Membrane

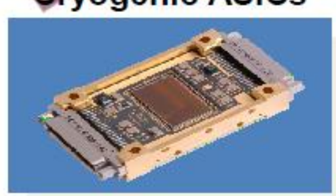


μShutters

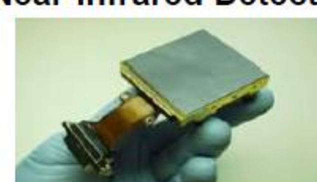


Cryocooler

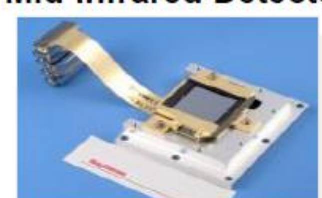
Cryogenic ASICs



Near-Infrared Detector

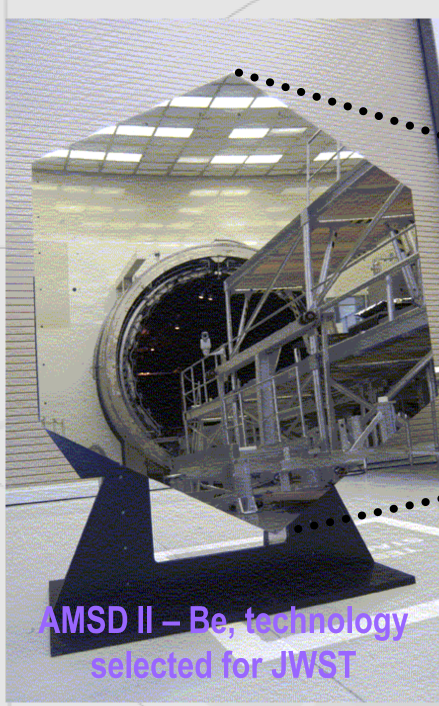


Mid-Infrared Detector

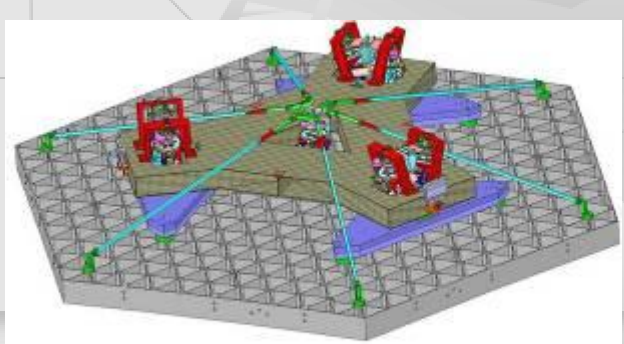


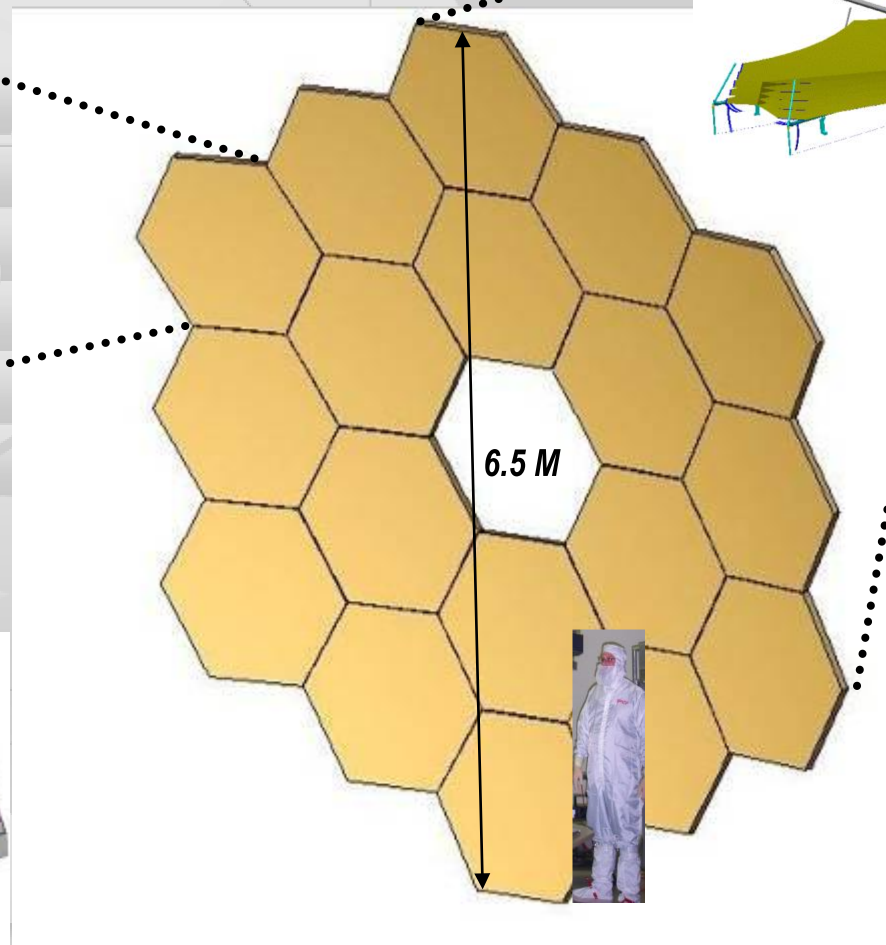
Technology Development of Large Optical Systems

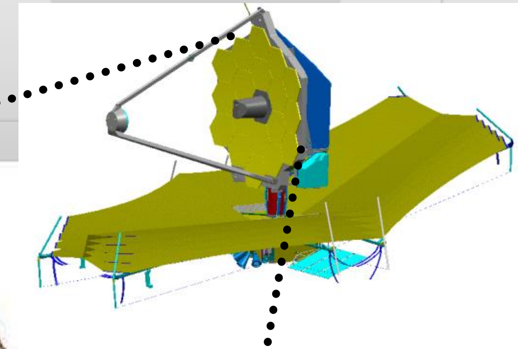
MSFC is the JWST Primary Mirror Segment Technology Development Lead for JWST



AMSD II – Be, technology selected for JWST







The 18 Primary Mirror segments

Observatory Performance

Observatory Performance Requirements

- Strehl Ratio:
  - > 0.8 at λ = 2 μm
  - > 0.8 at λ = 5.6 μm
- Encircled Energy:
  - > 74% at λ = 1 μm within 150 milli-arcsec radius
- Encircled Energy Stability:
  - < 2.5% at λ = 2 μm within 80 milli-arcsec radius

Strehl Ratio requires 150 nm rms total WFE

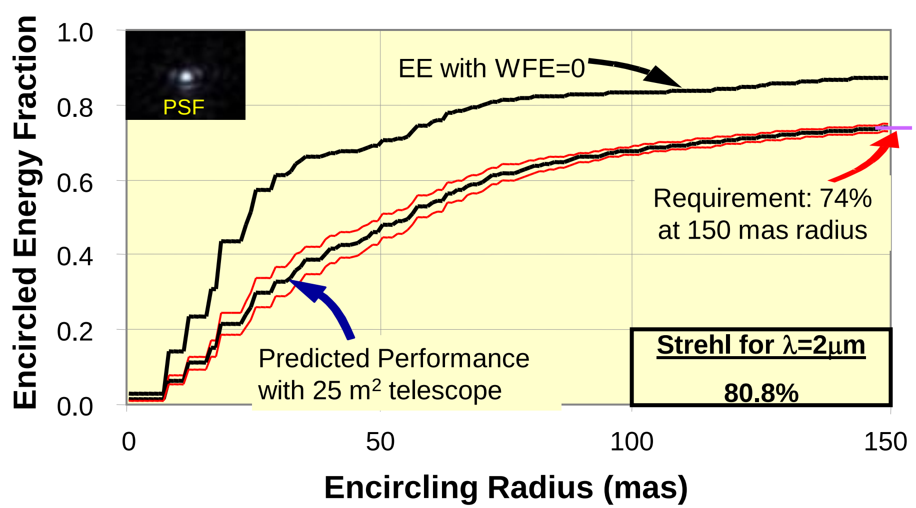
EE depends on 60 nm rms Mid & High Error

- WFE < ~ 5 cycles doesn't affect EE

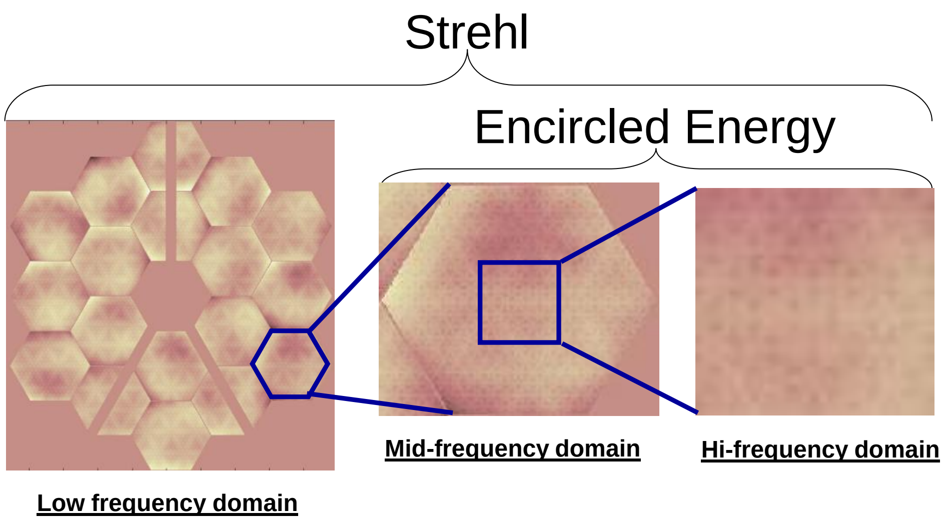
Active control of 18 hexagonal PM segments

- 6 DoF control of PM segment positions
- 1 DoF control of PM segment radius of curvature
- This provides active control of the low spatial frequencies up to nominally 5 c/a

PMSA Phase Error effects both Strehl & EE



Curves show Mean ± 1σ Encircled Energy Fraction for λ=1μm from Monte Carlo simulations of allocated WFE and LOS jitter



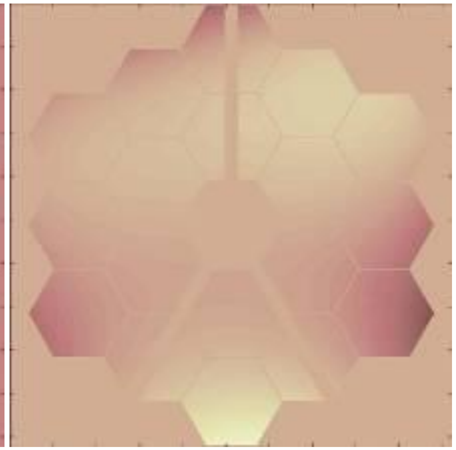
Total WFE Error Budget

- Observatory Wavefront Error 150 nm rms
  - Science Instruments 60 nm rms
  - Telescope 130 nm rms
    - OTS System Stability 60 nm rms
    - Wavefront Error 90 nm rms
      - Primary Mirror = 50 nm rms
      - Secondary Mirror = 50 nm rms
      - Tertiary Mirror = 40 nm rms
      - Fine Steering Mirror = 30 nm rms
      - System Alignment = 25 nm rms
    - Pointing Control 70 nm rms
  - WFSC 40 nm rms

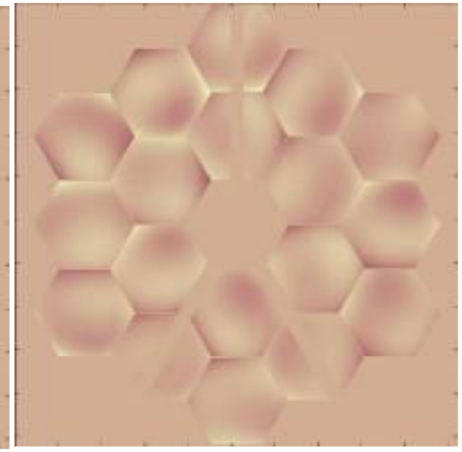
PM Wavefront Error is almost entirely Segment Figure Error

Observatory Wavefront Error

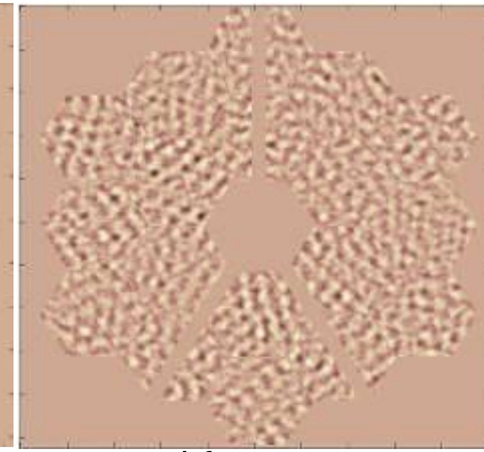
Total OPD



Low frequency
0 to 5 cycles/aperture



Mid-frequency
5 to 30 cycles/aperture



Hi-frequency
> 30 cycles/aperture

WFE is tracked by spatial frequency:

- Low spatial frequency = global aberrations
  - Controllable by SM 6DOF alignment and
  - PMSA piston, tilt, lateral adjust for Astigmatism & ROC adjust
- Mid spatial frequency
  - Individual PMSA positioning and low order aberrations
  - Partially controllable with PMSA 6DOF positioning & RoC control
- High spatial frequencies
  - Polishing residuals or local deformations at mounting locations
  - Not controllable by WFSC

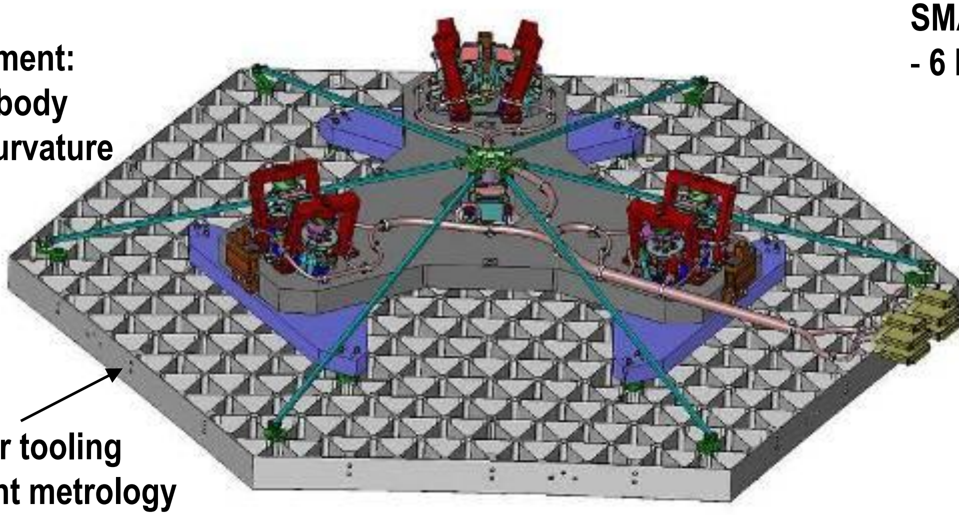
nm	OTE WFC Residual			
rms	tot	lo	mid	hi
Req	58	13	55	16
EOL	58	13	55	16

Req			EOL		
seg piston	5	nm	seg piston	5	nm
seg tilt	7	nr	seg tilt	7	nr
seg decent	100	nm	seg decent	100	nm
seg clock	217	nr	seg clock	217	nr
Seg Met.	10	nm	Seg Met.	10	nm
SM piston	100	nm	SM piston	100	nm
SM tilt	2	µr	SM tilt	2	µr
SM decent	2	µm	SM decent	2	µm
SM Met.	10	nm	SM Met.	10	nm

nm	Config. OTE Res			ote
rms	tot	lo	mid	hi
Req	99	83	52	16
EOL	99	83	52	16

PMSA & SMA Actively Controlled

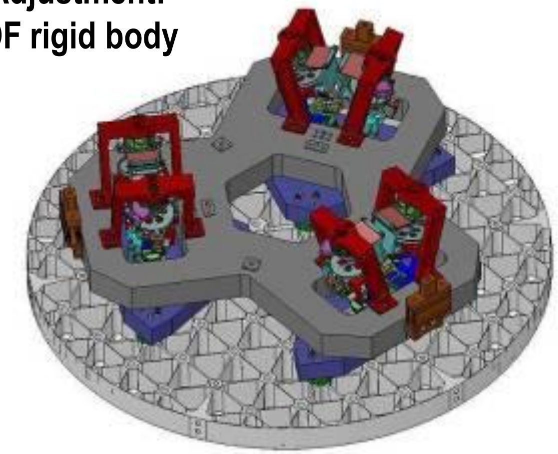
PMSA Adjustment:
- 6 DOF rigid body
- Radius of Curvature



Inserts for tooling
ball alignment metrology

Primary Mirror Segment Assembly

SMA Adjustment:
- 6 DOF rigid body



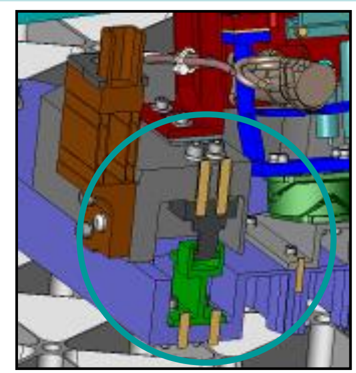
Secondary Mirror Assembly

PMSAs and SMA are in fabrication

Common Design Features

Bipod Actuator

Interface Mount



Lateral Launch Restraint
In Stowed Position

Mirror Technology has been demonstrated

time and maturity

Flight mirror demonstration

- Launch Load survival
- Acoustic tests

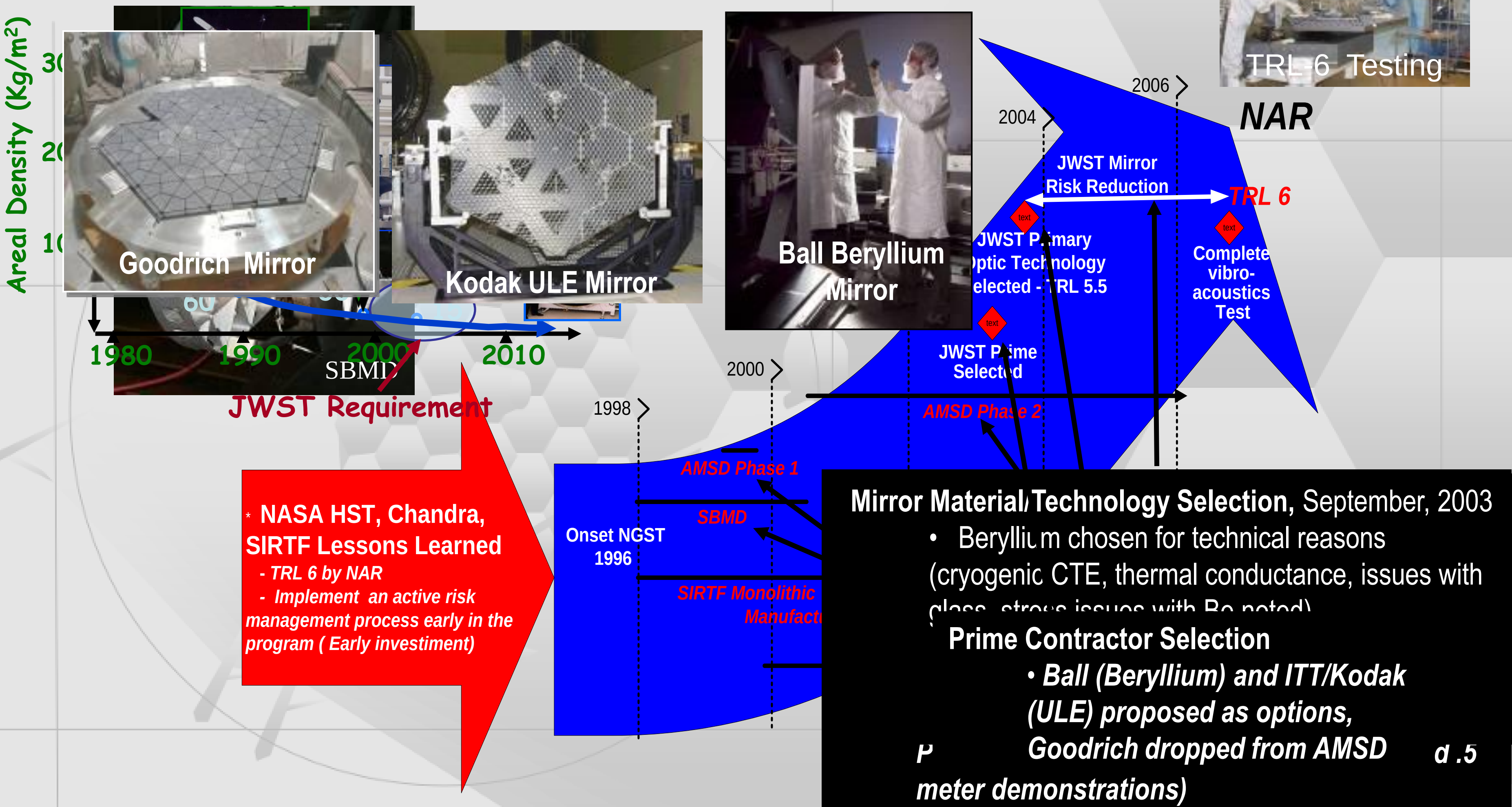
Advanced Mirror System Demonstr

- Areal density, full scale asphere
- Surface figure requirements
- Radius of curvature control
- Cryo-repeatability

Subscale Beryllium Mirror Demonstrator

- Areal density
- Cryo-figuring
- Radius of curvature control
- Cryo-testing of protected gold coati

JWST Mirror Technology History



Based on lessons learned, JWST invested early in mirror technology to address lower areal densities and cryogenic operations

AMSD – Ball & Kodak

Specifications

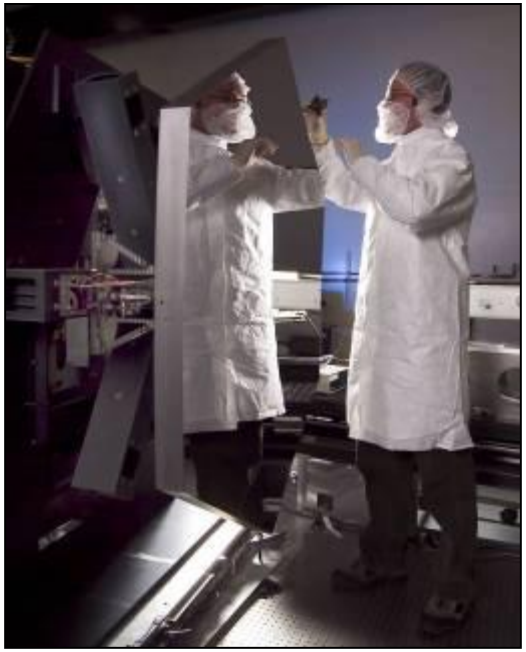
Diameter	1.4 meter point-to-point
Radius	10 meter
Areal Density	< 20 kg/m2
Areal Cost	< $4M/m2

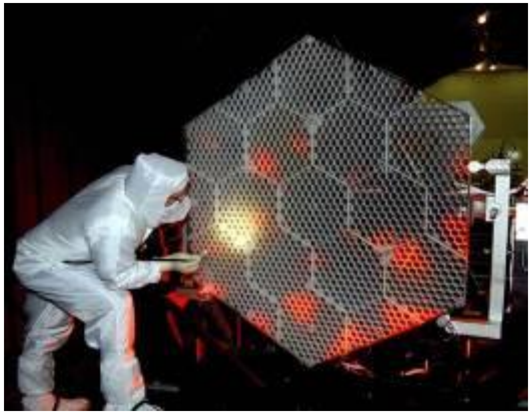
Beryllium Optical Performance

Ambient Fig	47 nm rms (initial)
Ambient Fig	20 nm rms (final)
290K – 30K	77 nm rms
55K – 30K	7 nm rms

ULE Optical Performance

Ambient Fig	38 nm rms (initial)
290K – 30K	188 nm rms
55K – 30K	20 nm rms





Advantages of Beryllium

Very High Specific Stiffness – Modulus/Mass Ratio

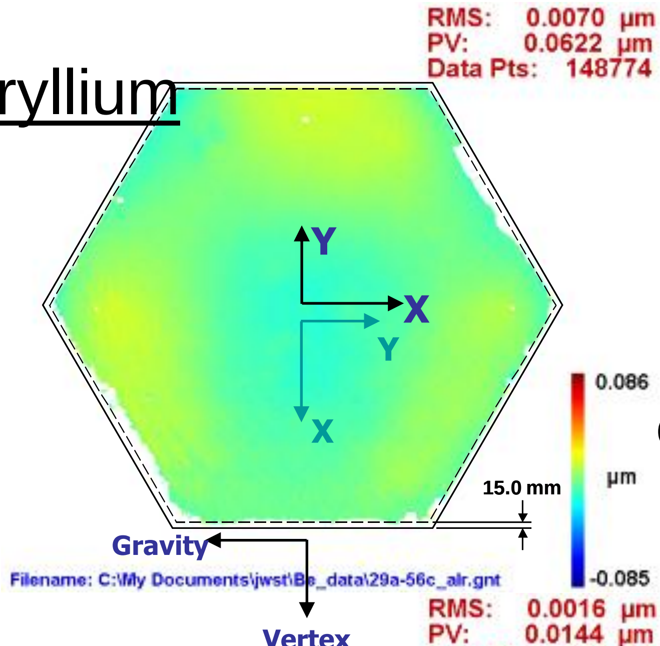
- Saves Mass – Saves Money

High Conductivity & Below 100K, CTE is virtually zero.

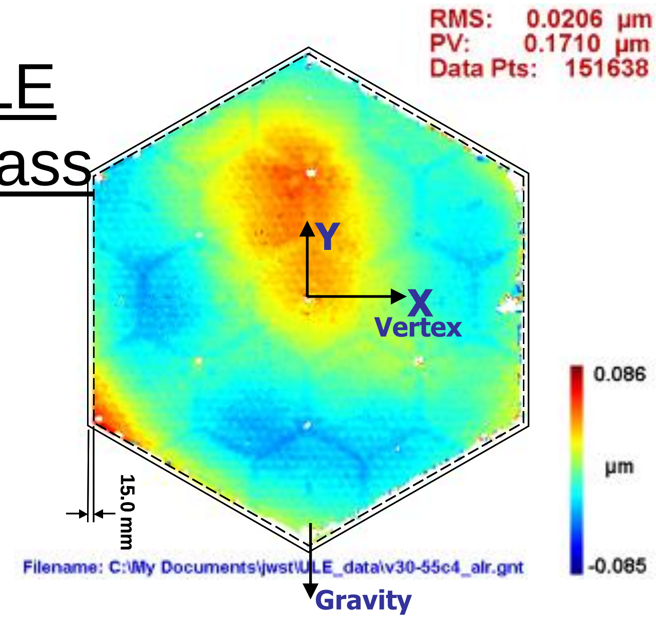
- Thermal Stability

Figure Change: *30-55K Operational Range*

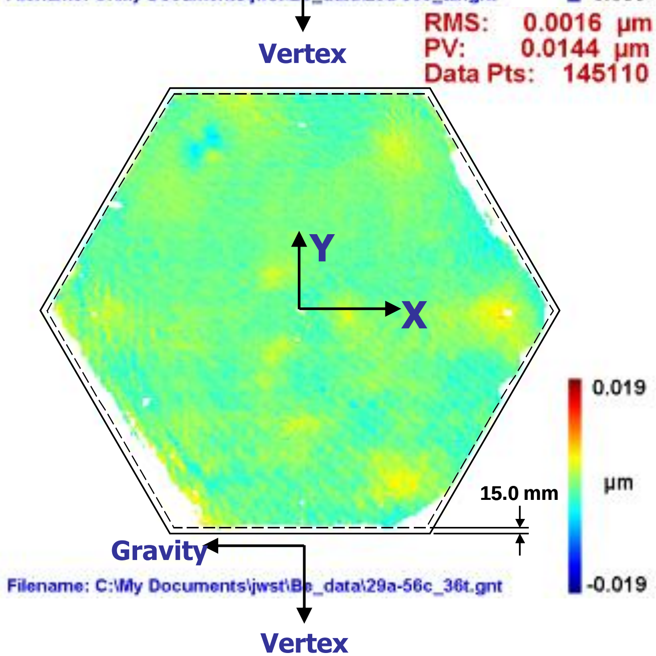
<u>Beryllium</u>



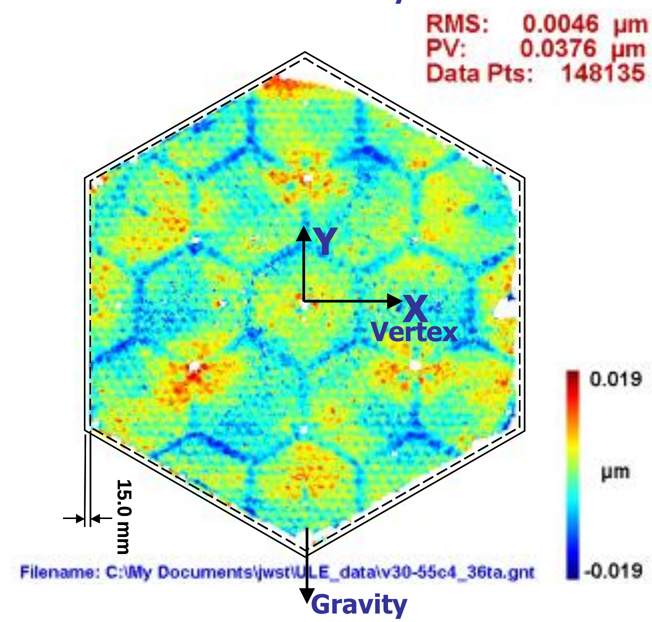
<u>ULE Glass</u>



Surface Figure With Alignment Compensati on



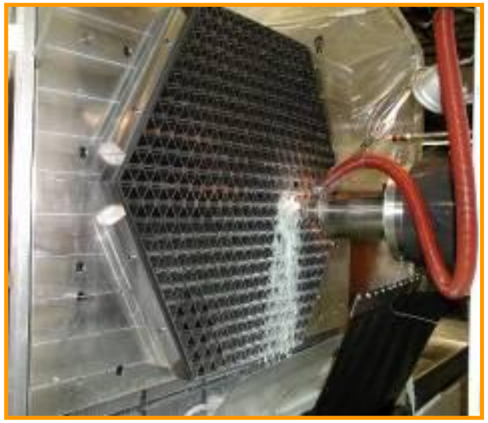
Residual with 36 Zernikes Removed



Mirror Manufacturing Process

Blank Fabrication

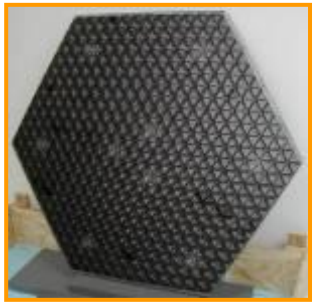
HIP Vessel being loading into chamber



Machining of Web Structure

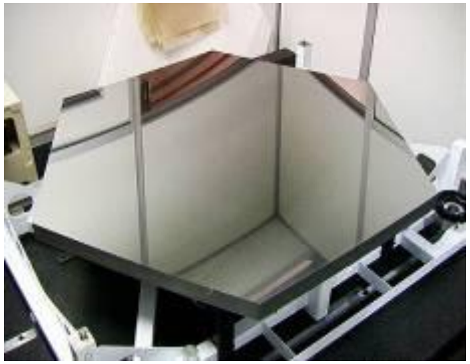
Machining

Machining of Optical Surface



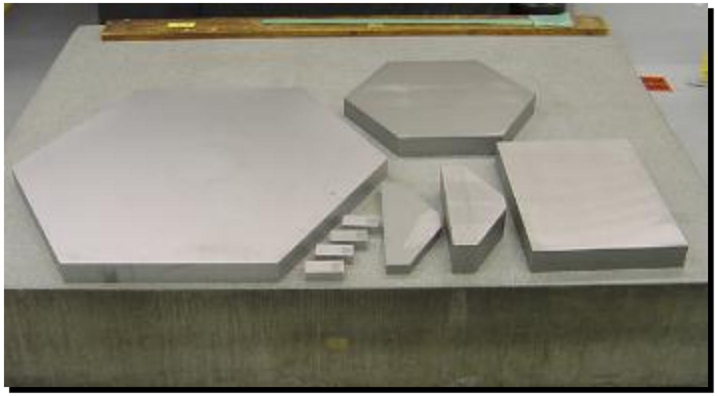
Completed Mirror Blank

Polishing



Mirror System Integration

Brush Wellman



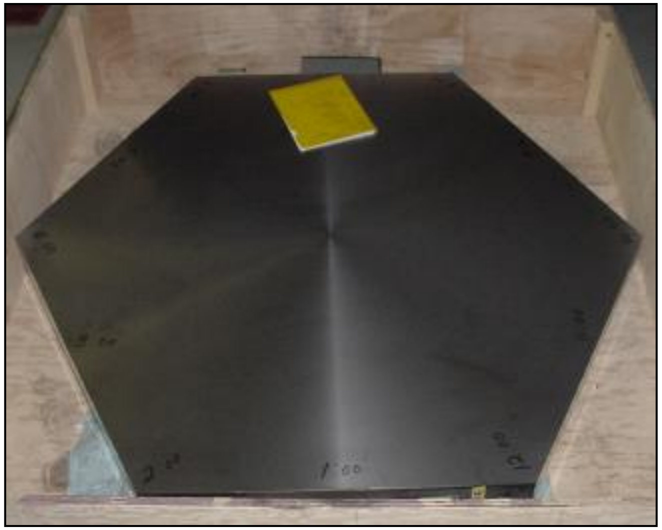
Substrate Fabrication

PM Segments SN 19-20
powder in loading container

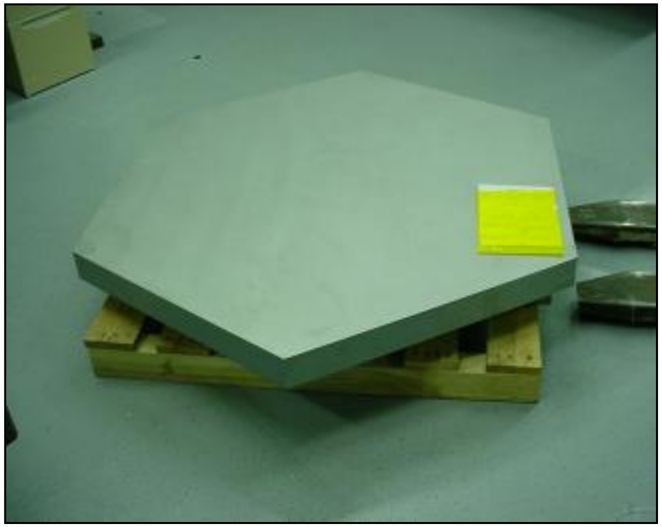
PM Segments SN 19-20
HIP can prepared for powder loading

PM Segments SN 19-20
loaded HIP can in degas furnace

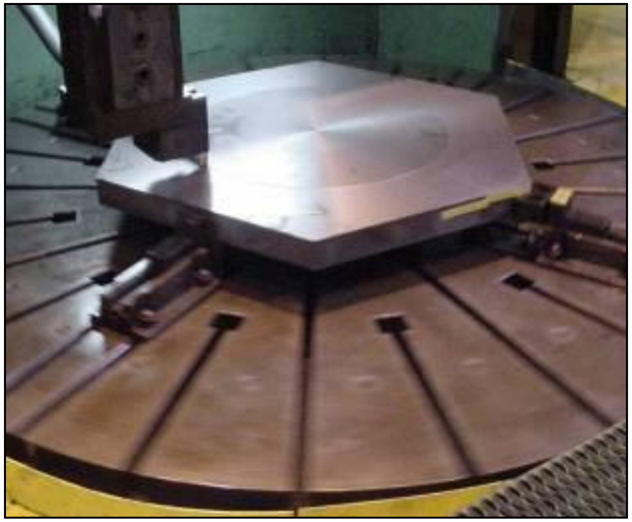
Quality Control X-Ray Inspection



PM Segment SN 17 after finish machining



PM Segment SN 17 after x-ray



PM Segment SN 18 during finish machining

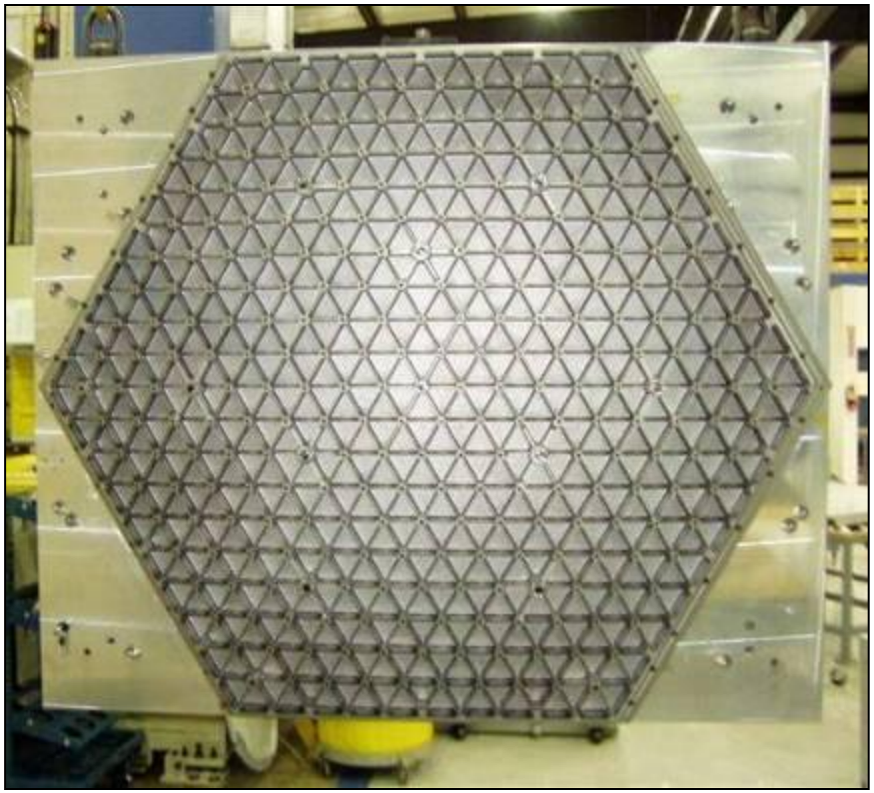
PM Segment SN 18 during x-ray

Axsys Technologies

8 CNC Machining Centers

Axsys Technologies

PMSA Engineering Development Unit

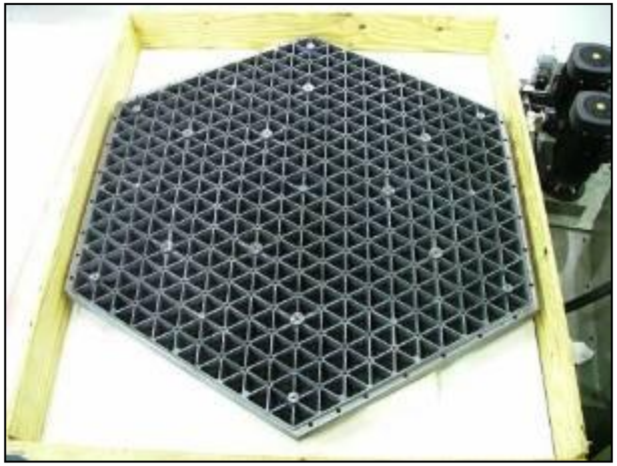


PMSA EDU rear side machined pockets

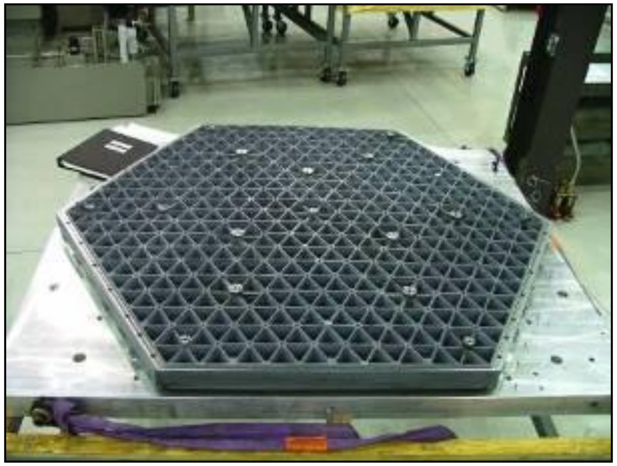
PMSA EDU front side machined optical surface

Axsys Technologies

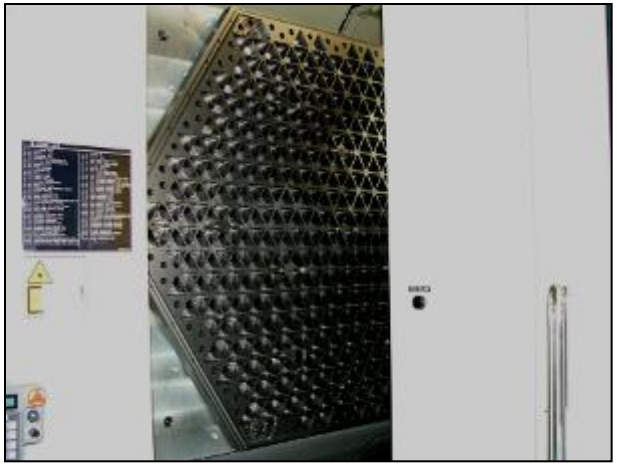
Batch #1 (Pathfinder) PM Segments



PMSA #1 (EDU-A / A1)



PMSA #2 (3 / B1)



PMSA #3 (4 / C1)

Batch #2 PM Segments

PMSA #4 (5 / A2)

PMSA #5 (6 / B2)

PMSA #6 (7 / C2)

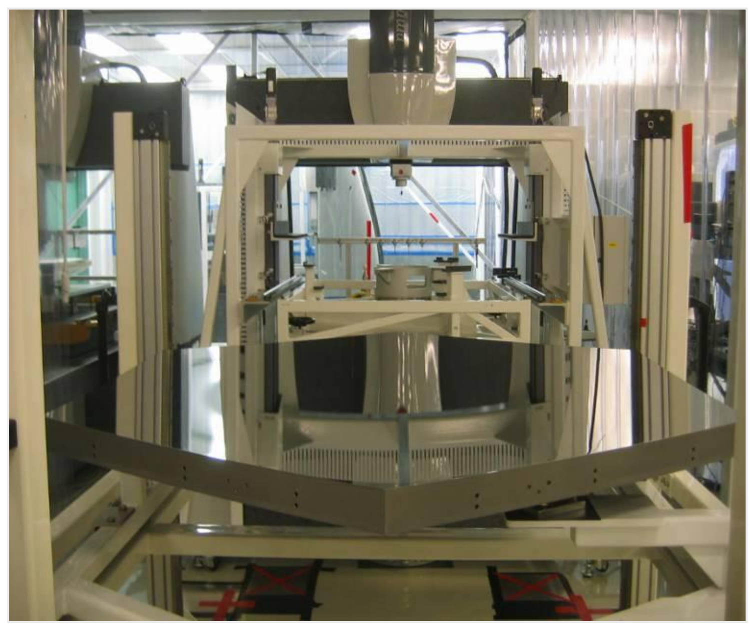
Tinsley Laboratories

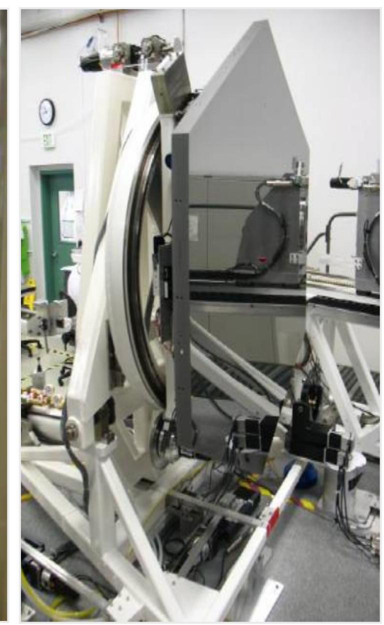
Production Preparation – CCOS Machines

- 1^{st} – 4^{th} CCOS machine bases assembled and operational
- 5^{th} – 8^{th} CCOS machines received and in storage – installation to start 4/4/05

Telescope mirror polishing is underway

PMSA EDU

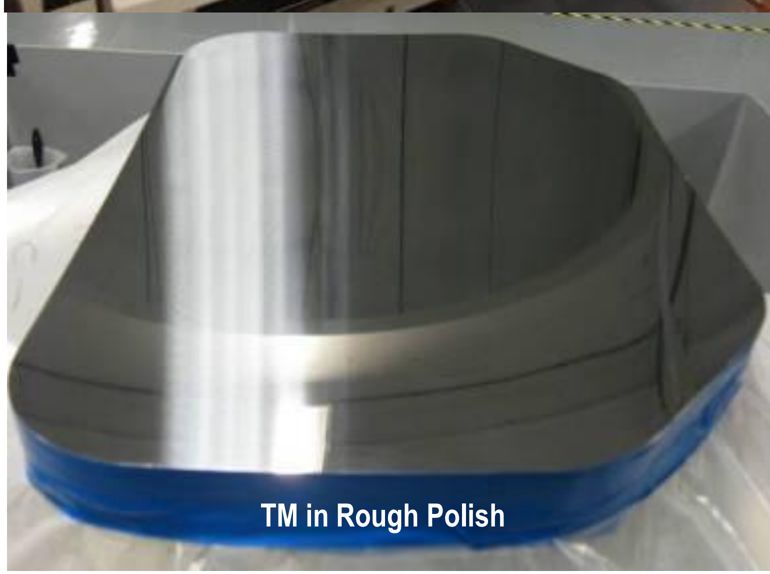




Mirror Fabrication Status at L-3 SSG-Tinsley

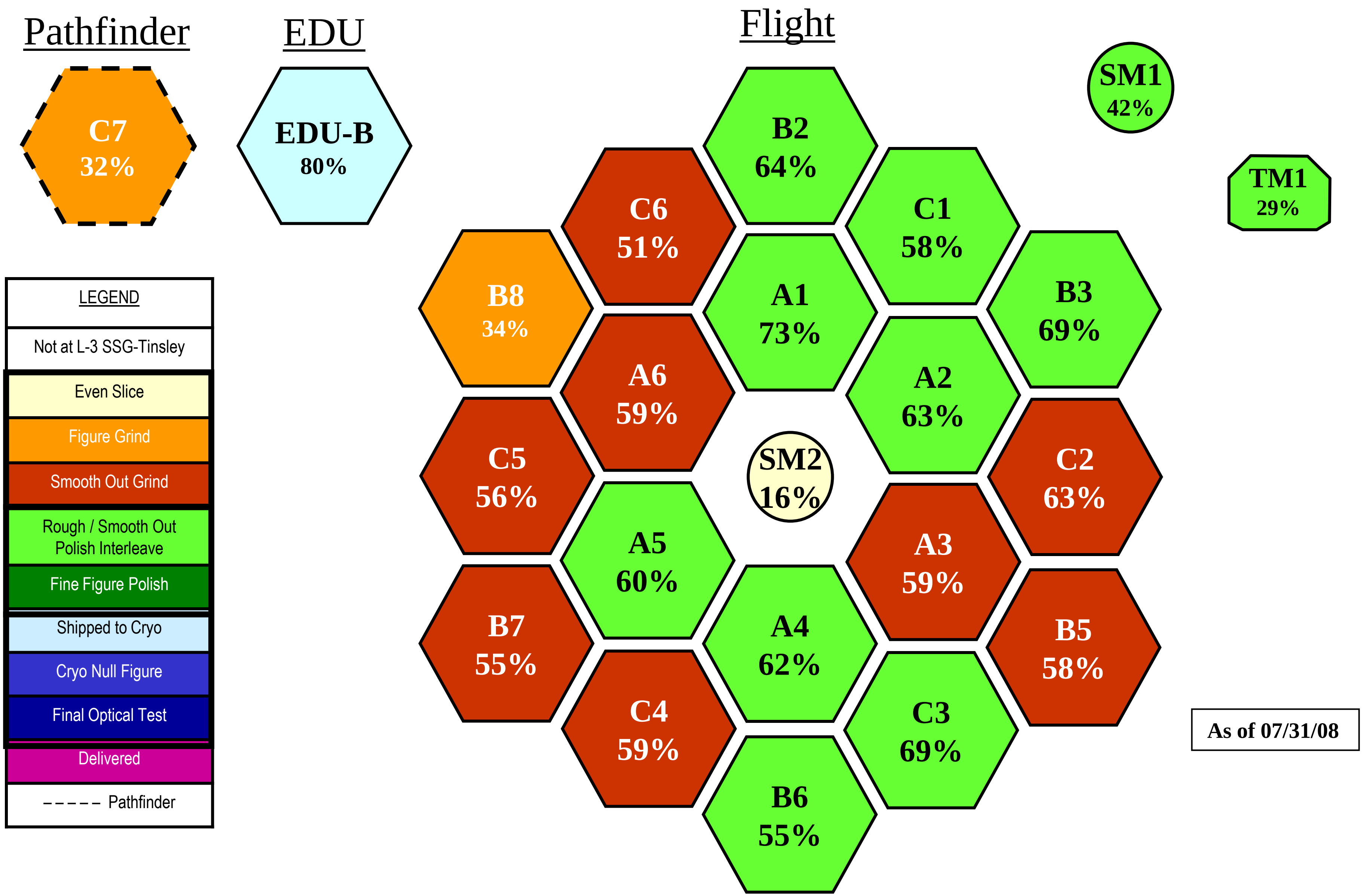

Primary Mirror EDU Post Fine Polish


SM in Rough Polish

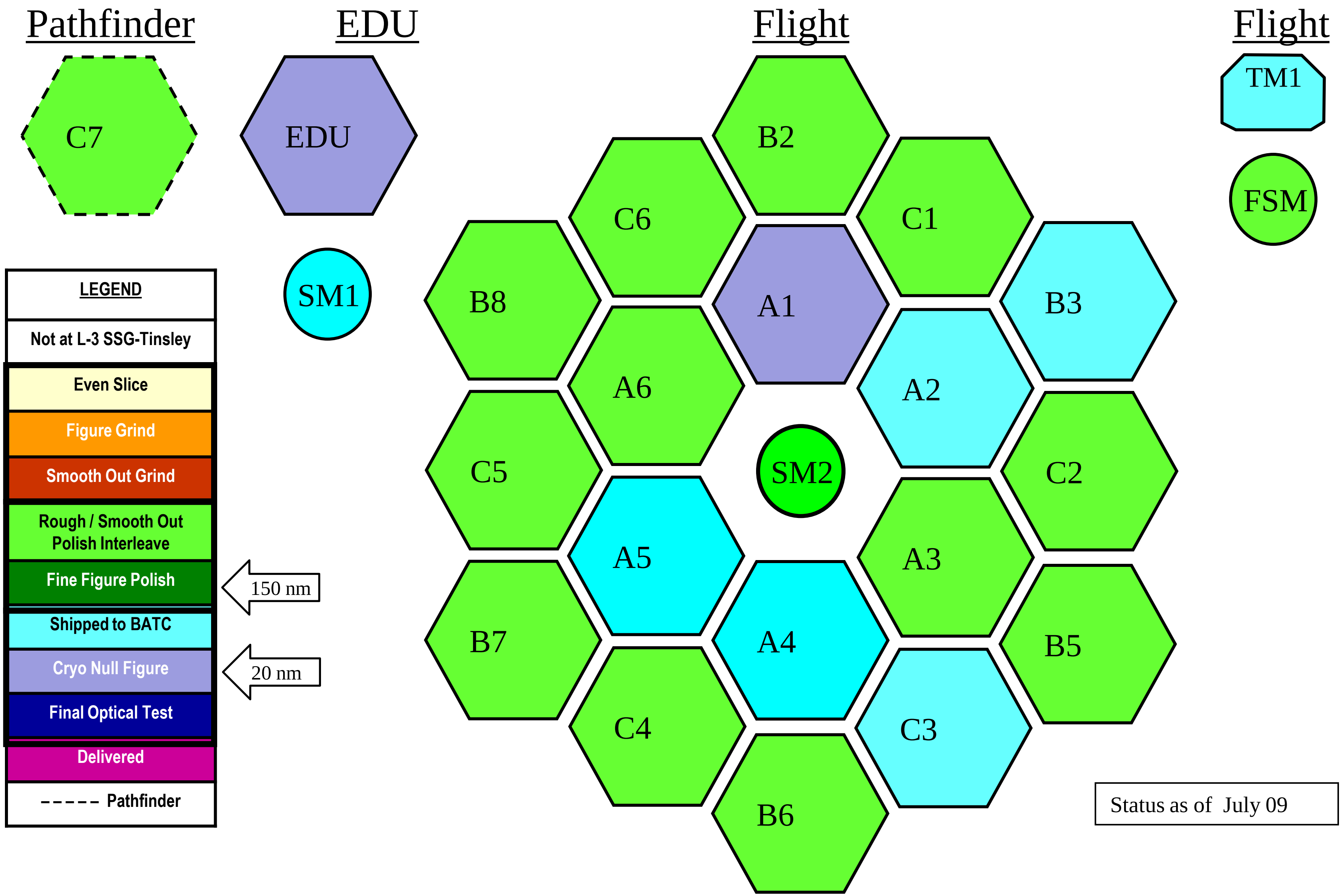

TM in Rough Polish

EDU Shipped to BATC for Cryo Testing

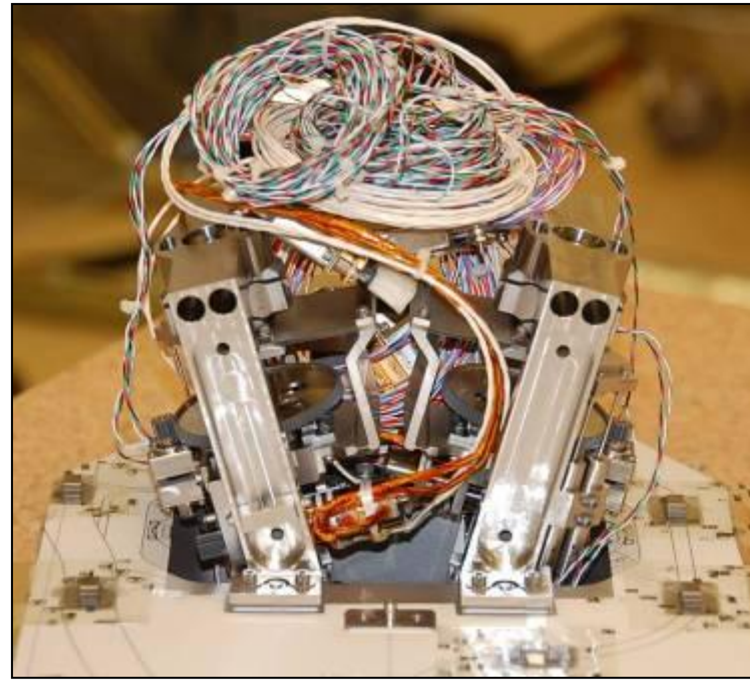
Mirror Fabrication Status at L-3 SSG-Tinsley – July 08

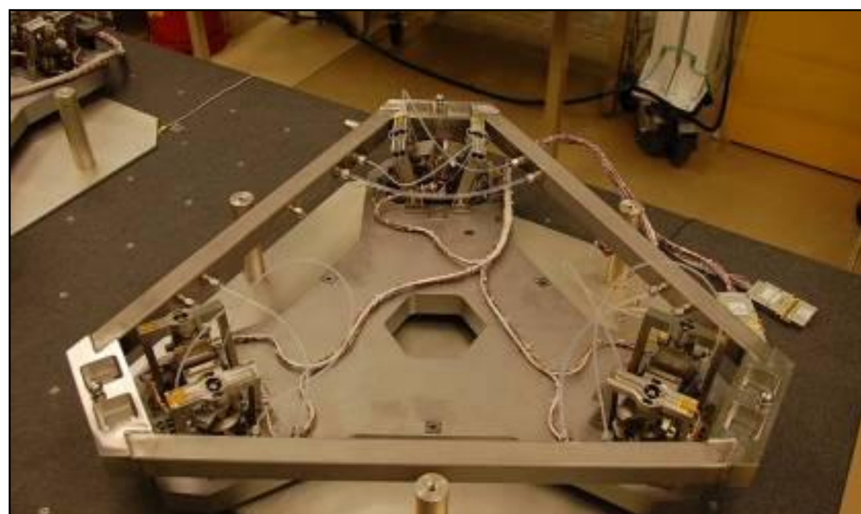


Mirror Fabrication Status at L-3 SSG-Tinsley – July 09

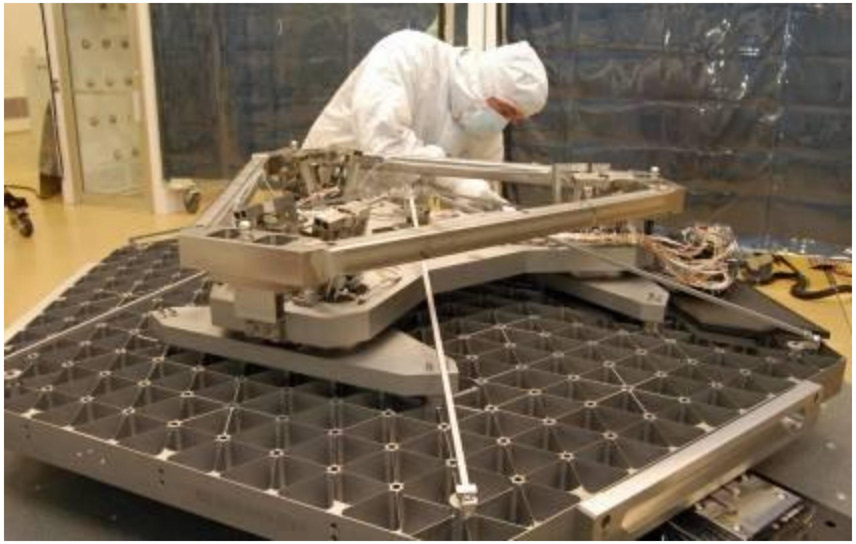
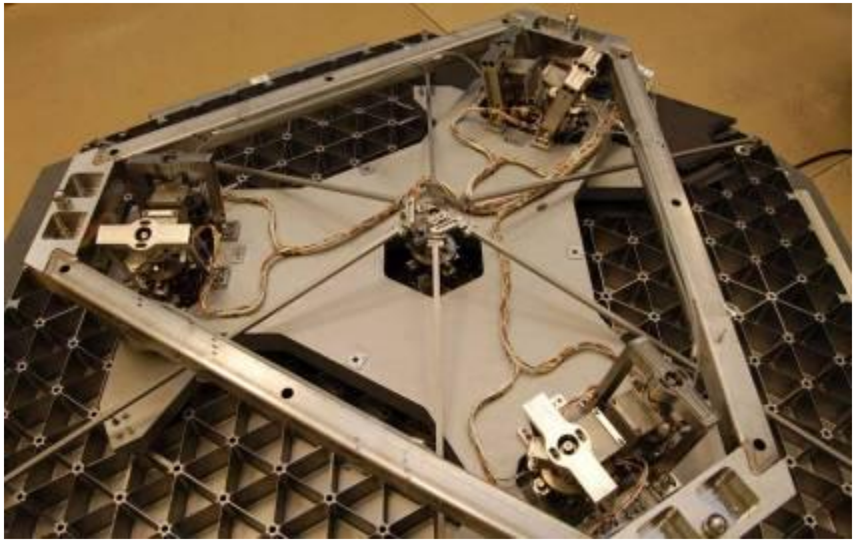
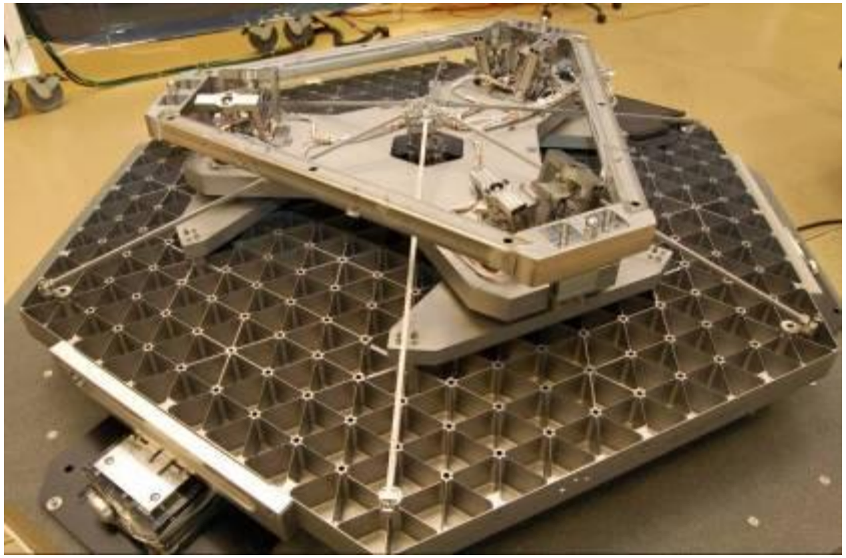
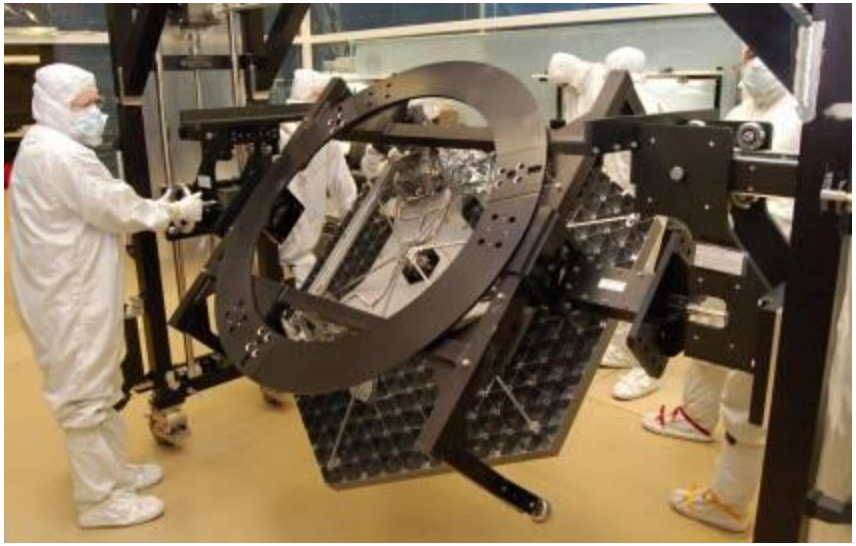


Hexapod assemblies in manufacturing and on schedule

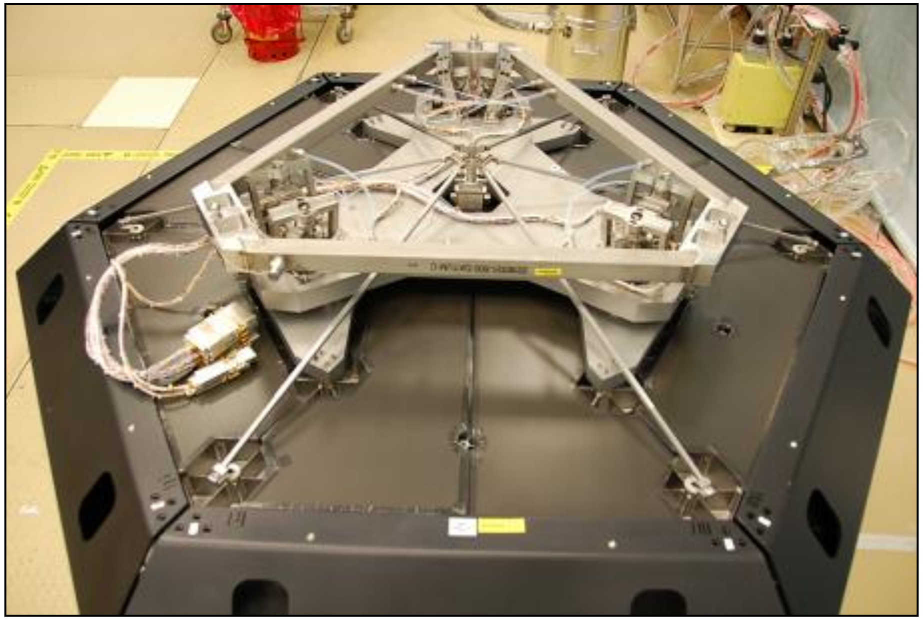


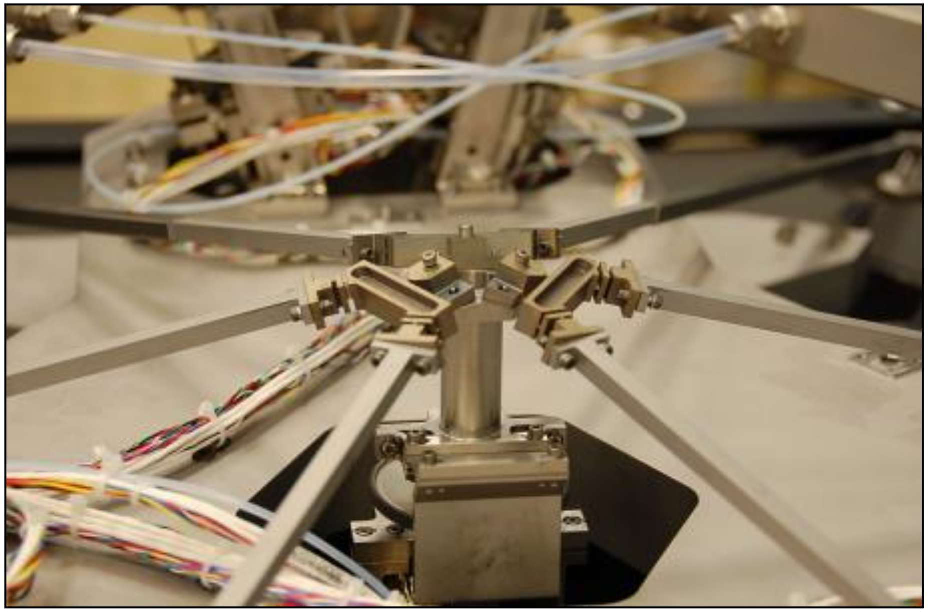


Primary Mirror Segment Assembly (PMSA)

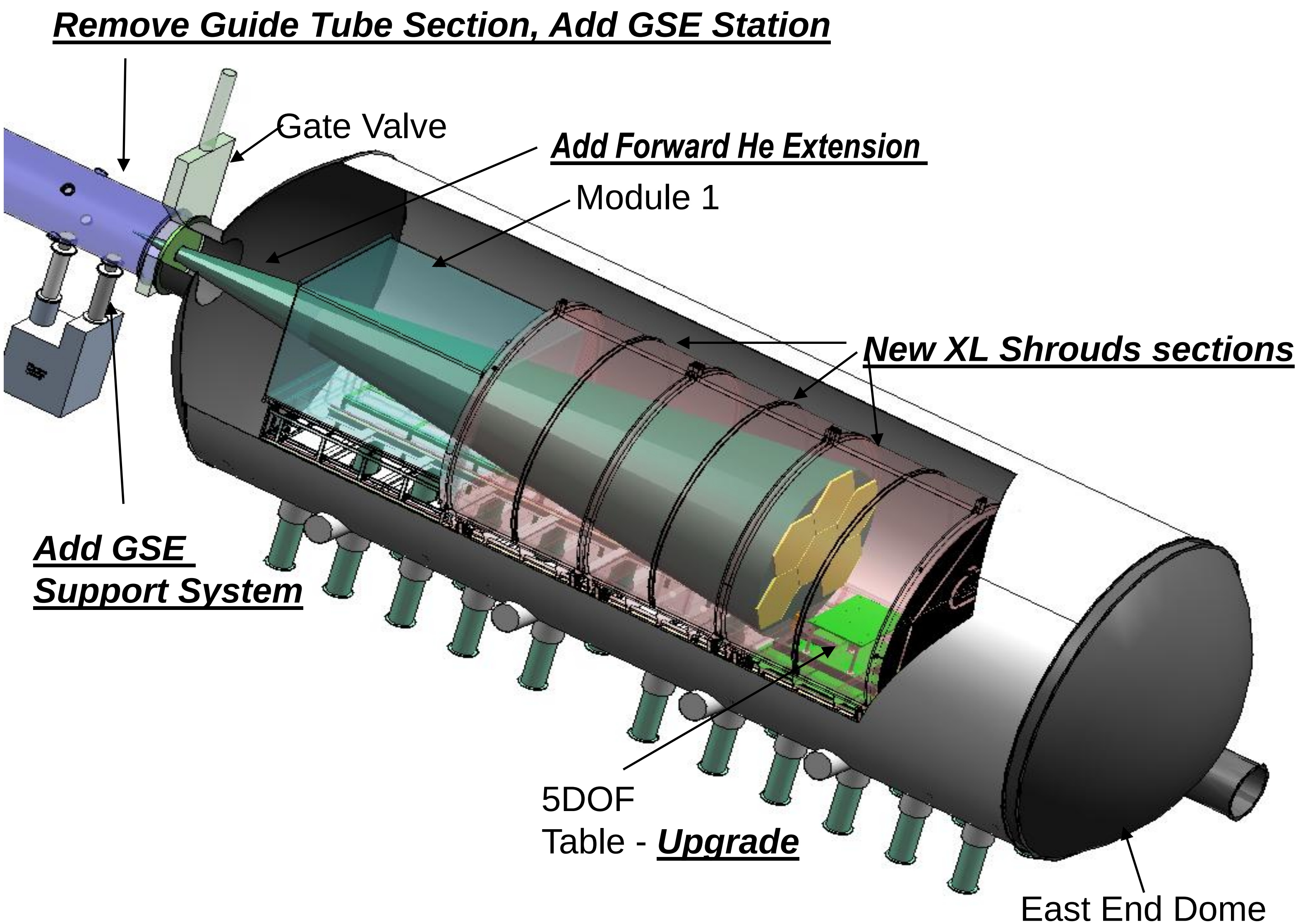





EDU PMSA in assembly for cryo-testing

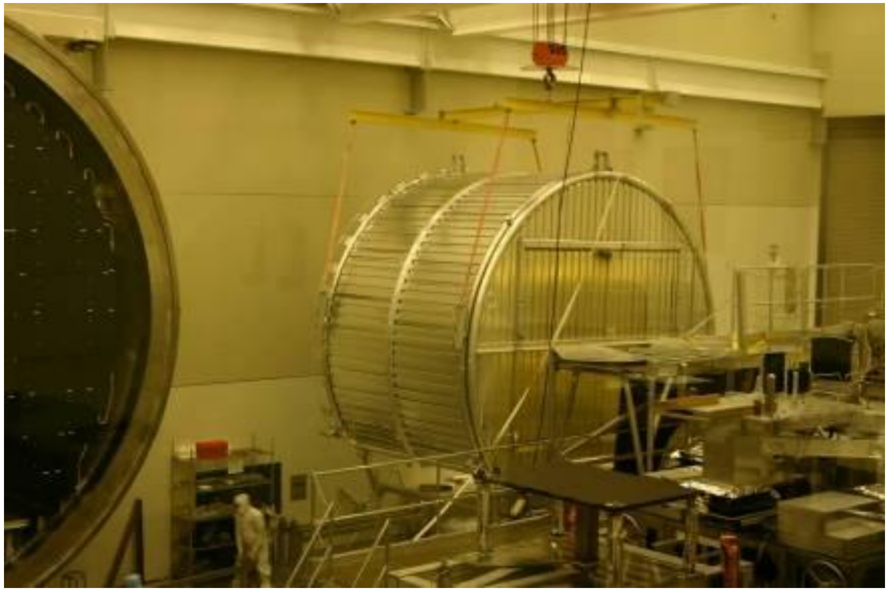


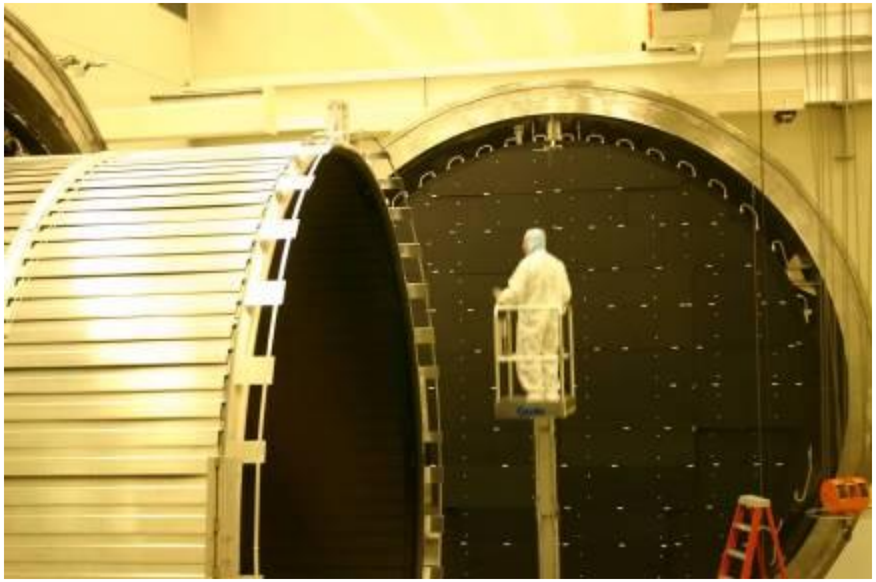


MSFC Cryogenic Test Facility

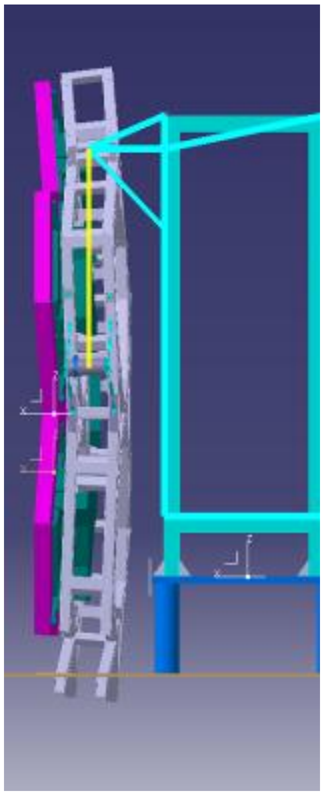


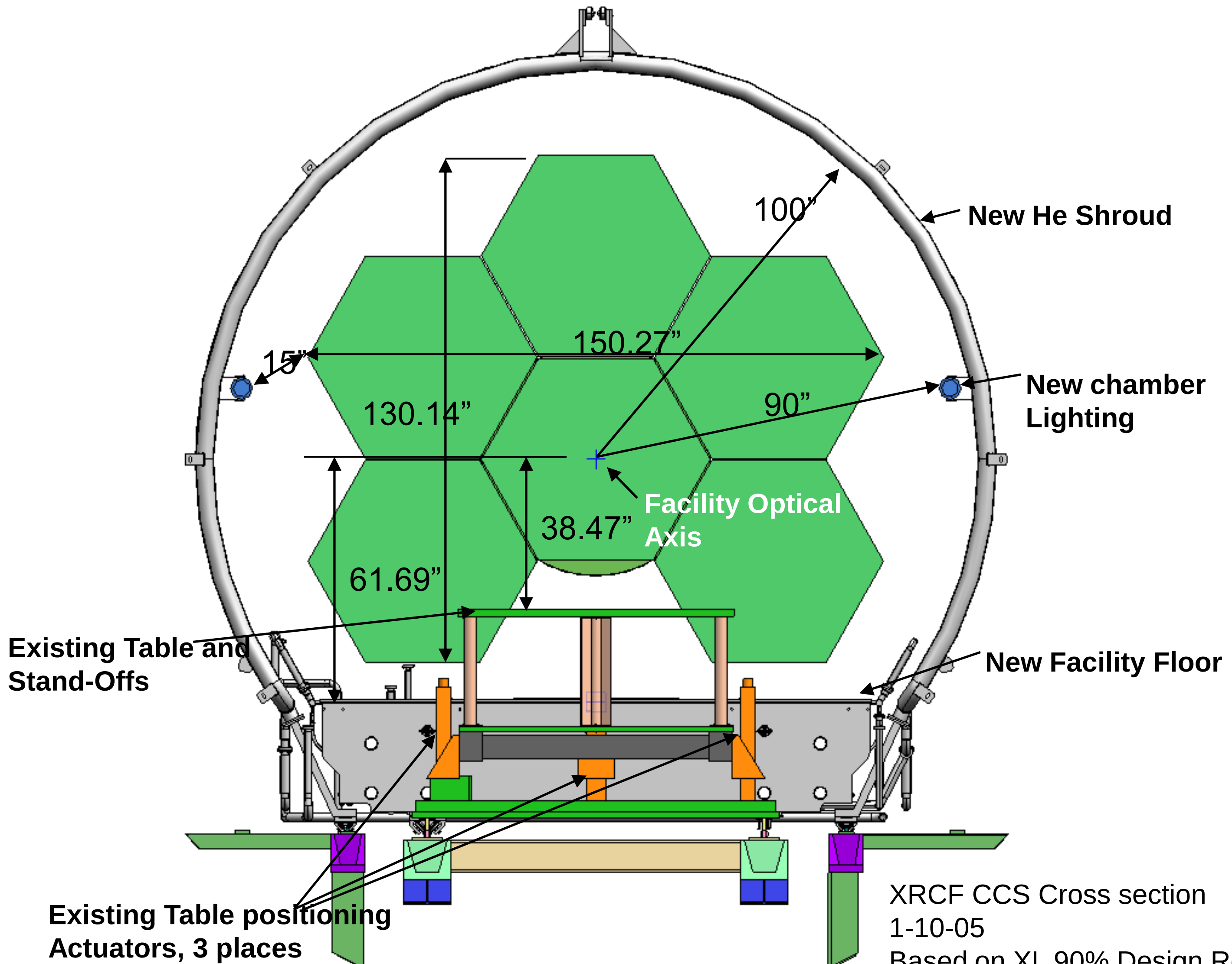
XRCF Cryo-Shroud Fit- Check





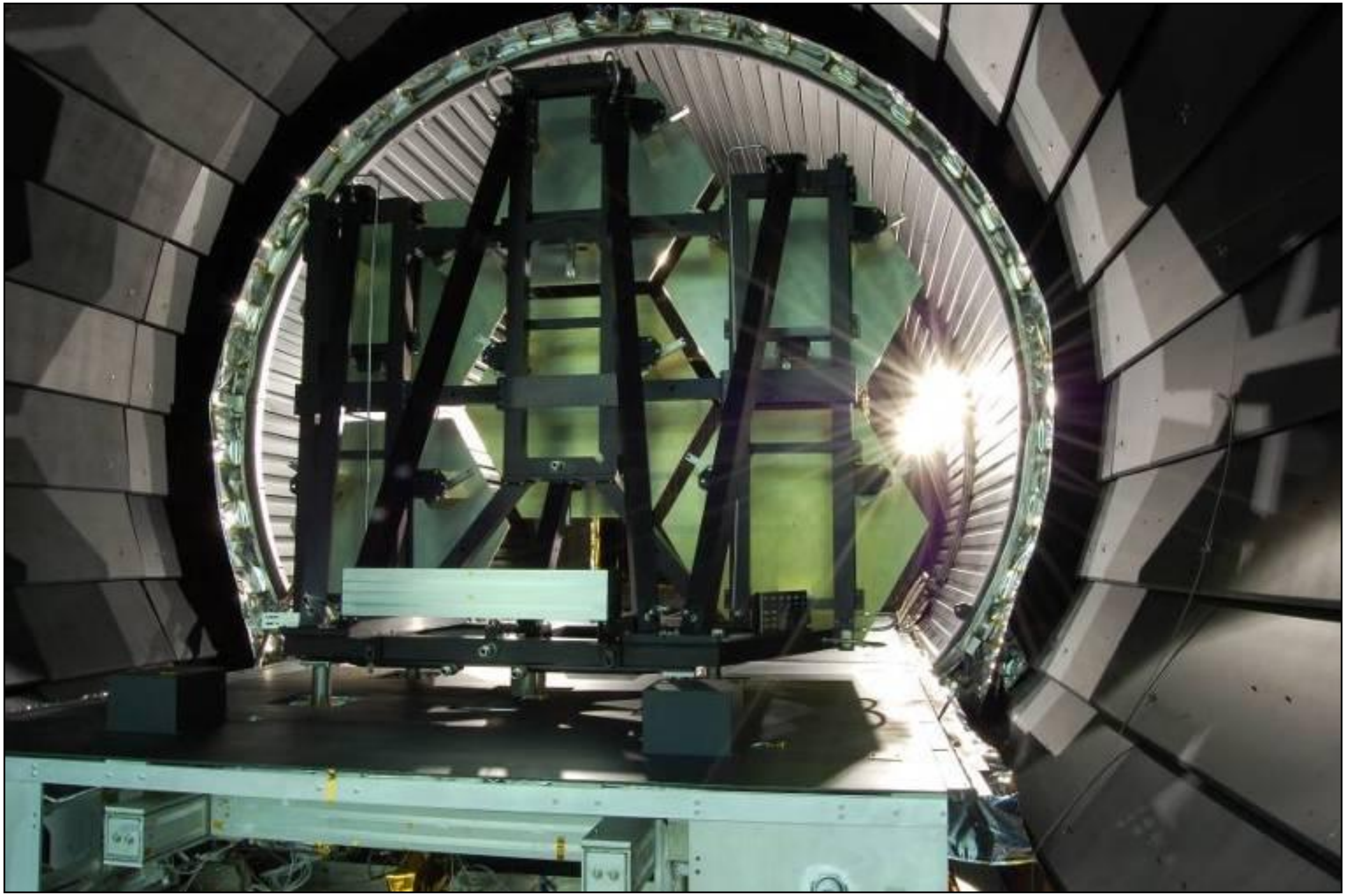
MSFC Cryogenic Test Stand





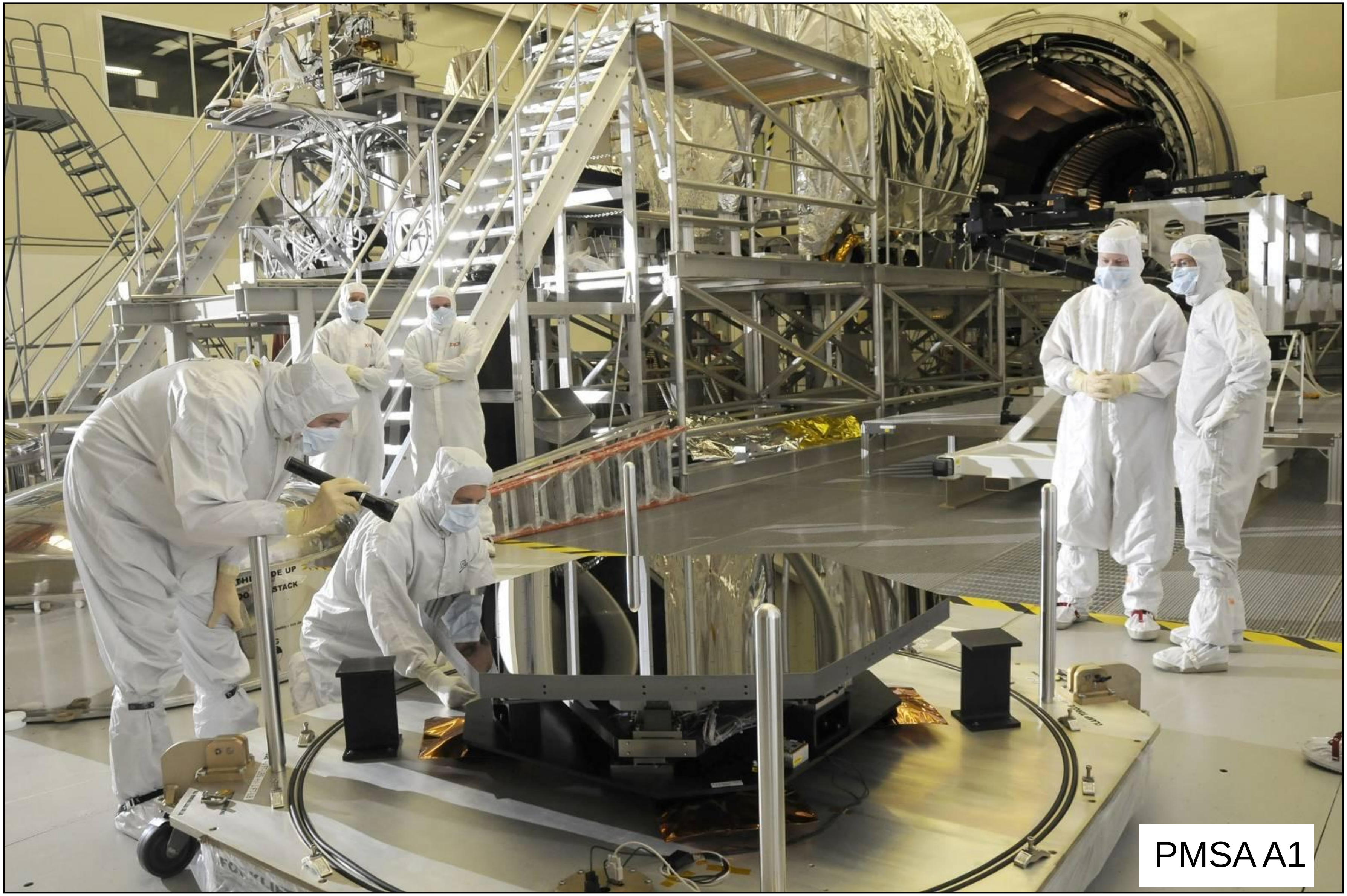
XRCF CCS Cross section
1-10-05
Based on XL 90% Design Review Data

MSFC Cryo-Test

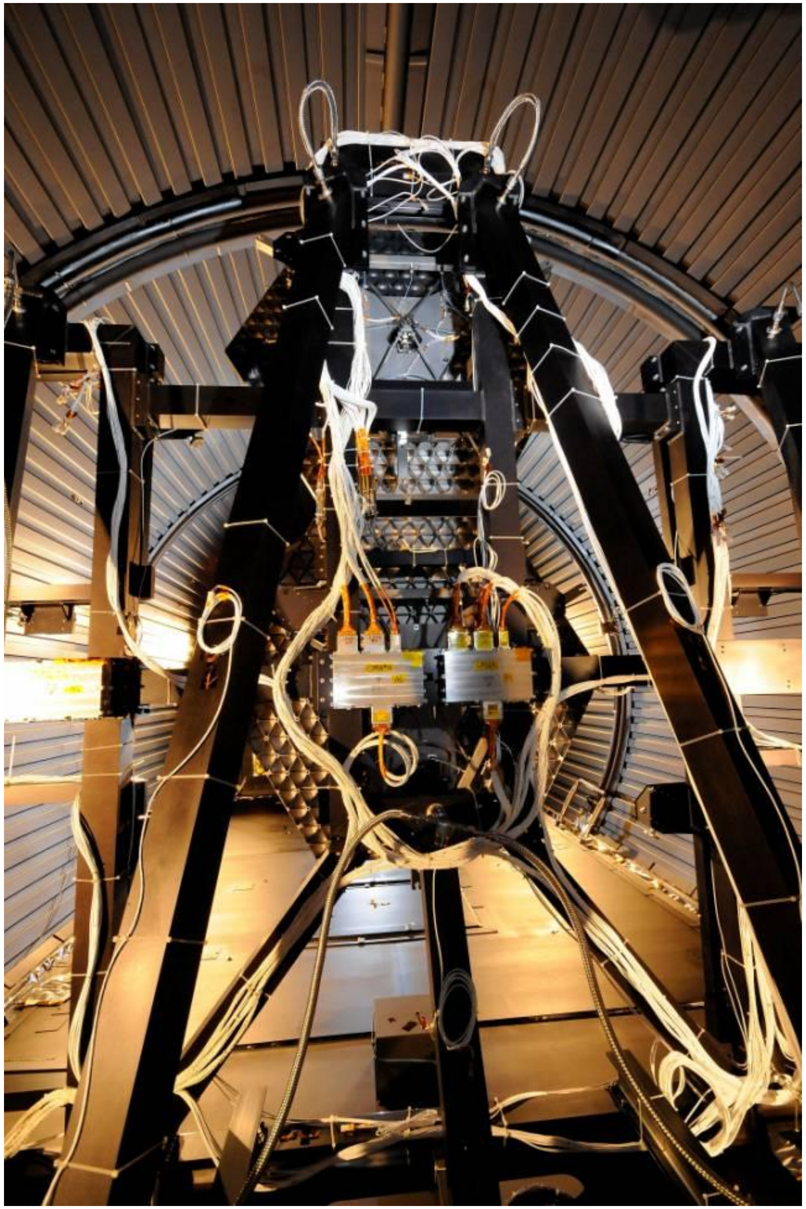


GSE PMSA Test Stand Cryo Certification Testing at XRCF

The first flight mirror segment at the XRCF at MSFC

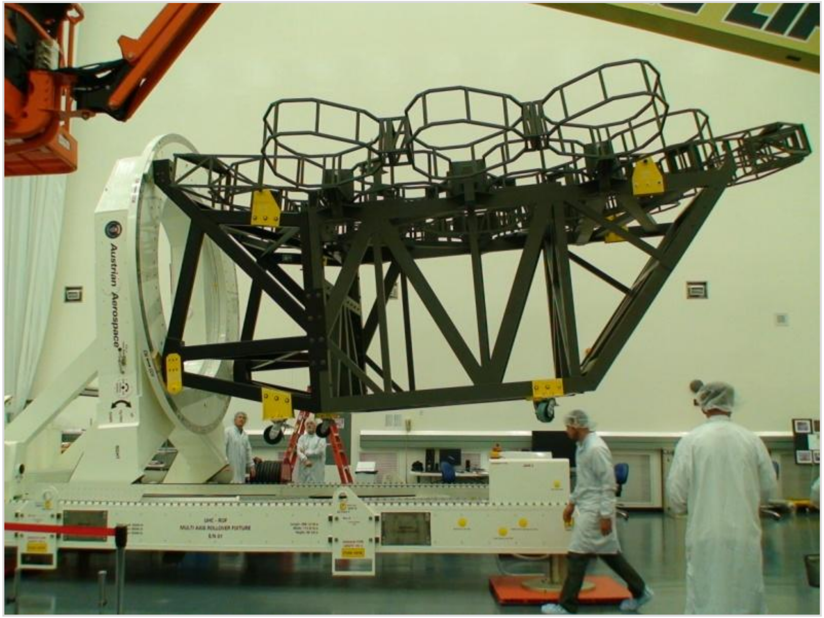


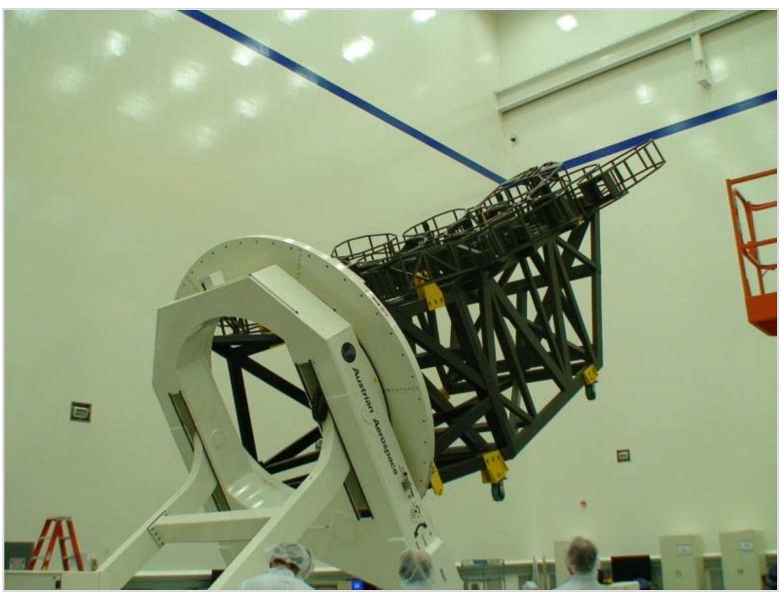
EDU and A1 PMSAs in the XRCF chamber at MSFC

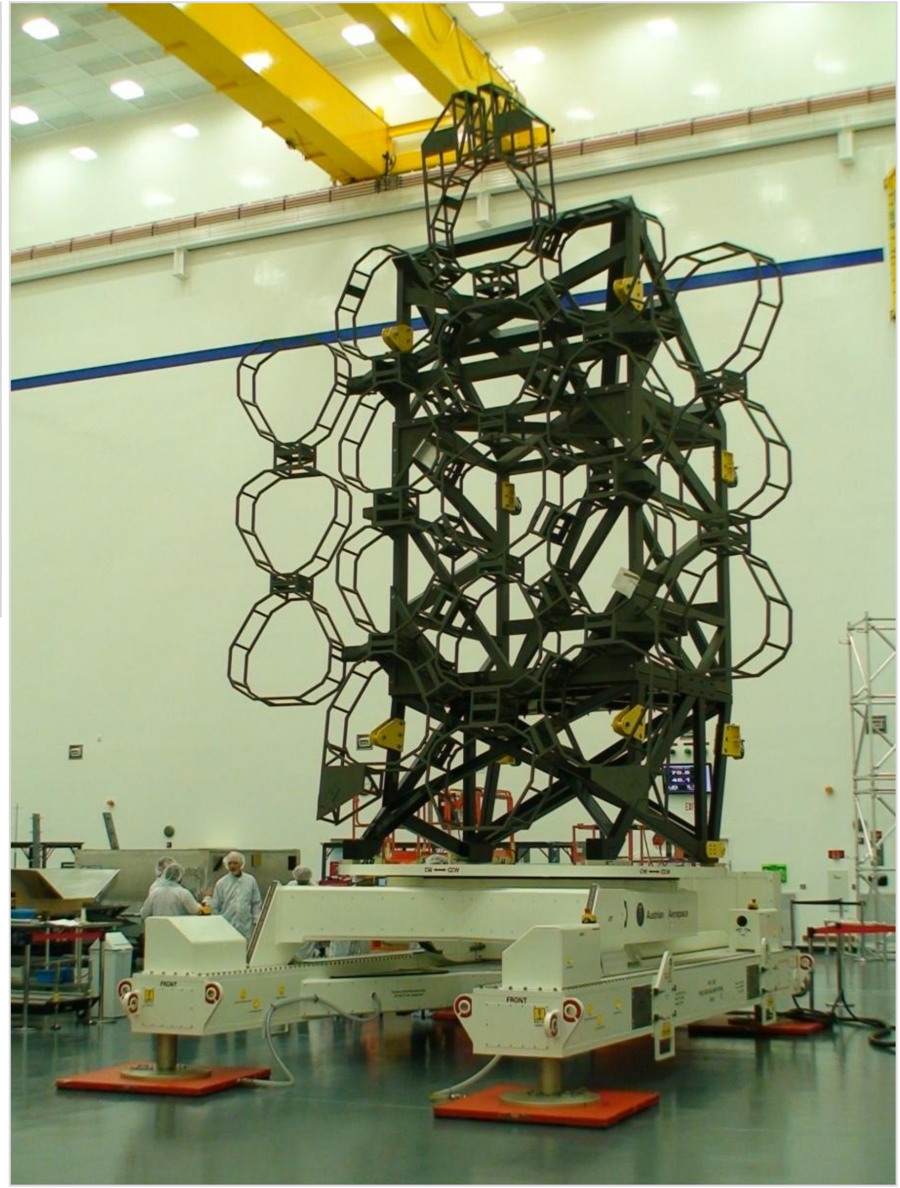


Buildup of telescope flight structure underway at ATK

Full scale OTE mockup in handling test at NGAS



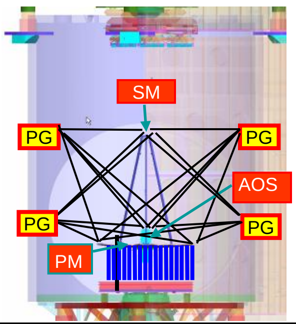




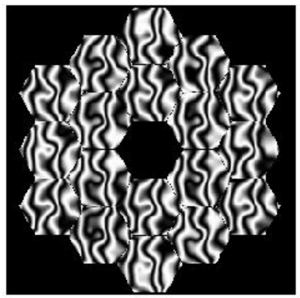
Observatory level testing occurs at JSC Chamber A

Verification Test Activities in JSC Chamber-A

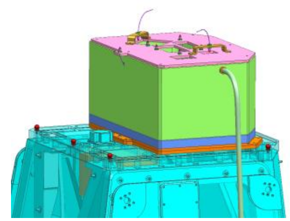
Cryo Position Metrology



Primary Mirror Stability Test

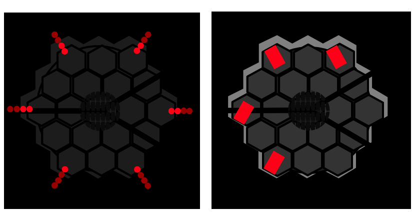


Focus Sweep Test (inward facing sources)

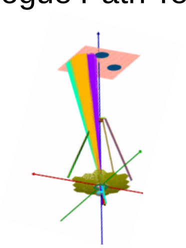


Crosscheck Tests in JSC Chamber-A

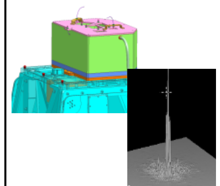
Pupil Alignment Test



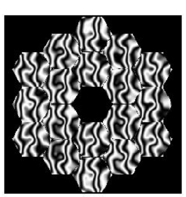
Rogue Path Test



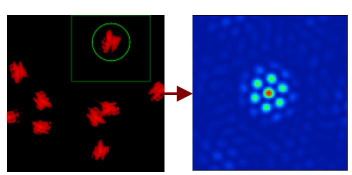
Pass-and-a-Half Test

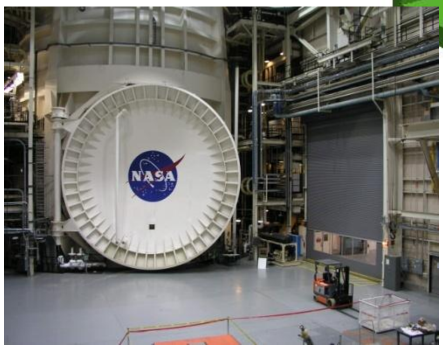


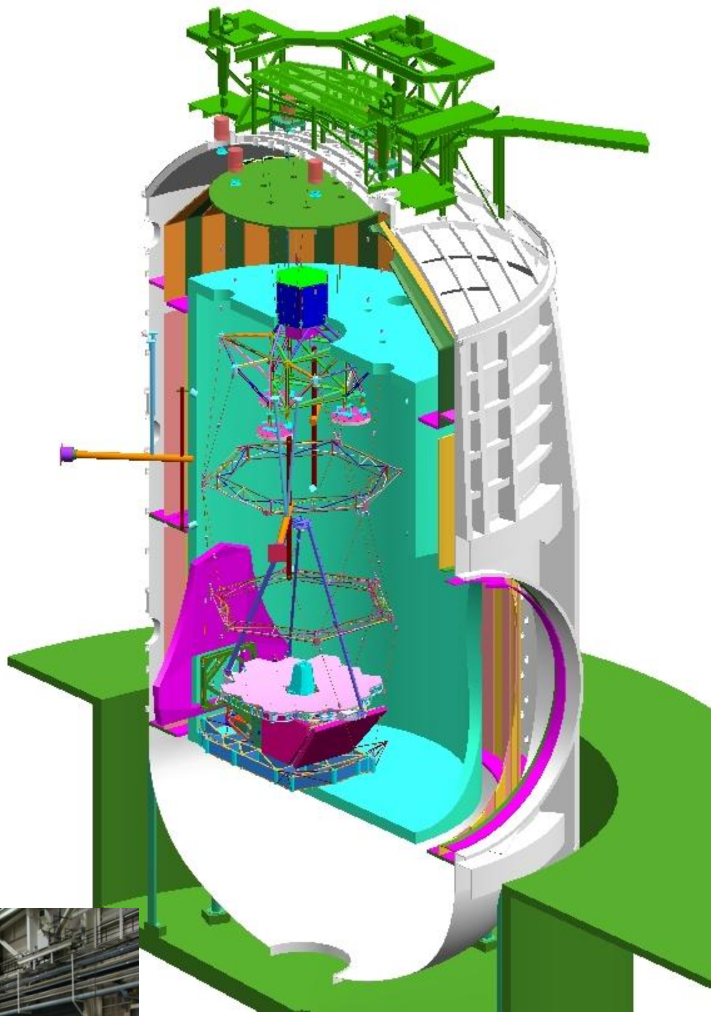
Primary Mirror WFE Test



End-to-End WFSC Demonstration







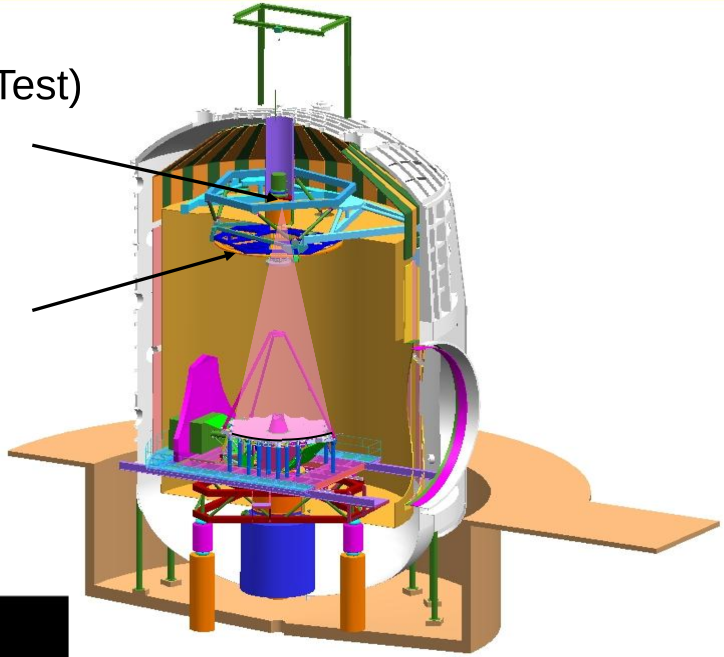
<u>Chamber A:</u>

- 37m tall, 20m diameter, 12m door
- LN2 shroud and GHe panels

Primary Mirror Testing

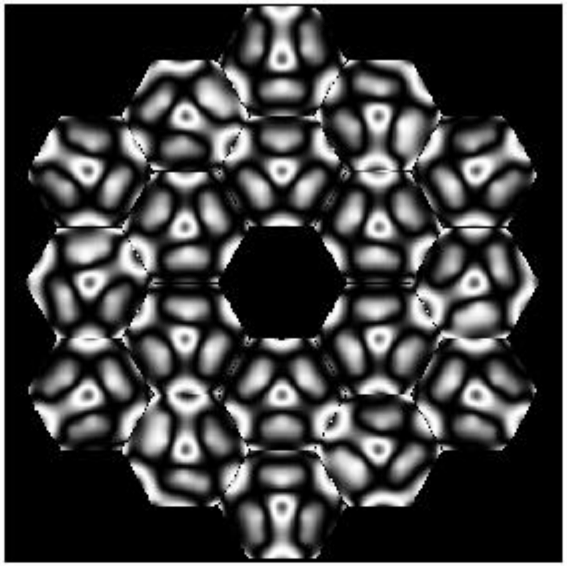
Center of Curvature Optical Assembly (COCOA) (PM Test)
- Multi Wavelength Interferometer
- Reflective Null Lens
- 6 DOF Position Drive

Object Surface Optical Assembly (OSOA) (ACFs)

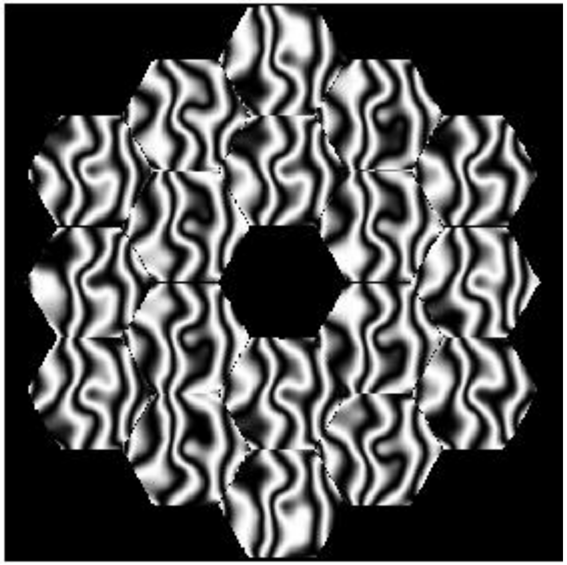


Predicted PM 1g Gravity Deformation

~200 nm rms WFE (~1.5 λ PV @ 632 nm)



Nulled Interferogram (λ=632 nm)

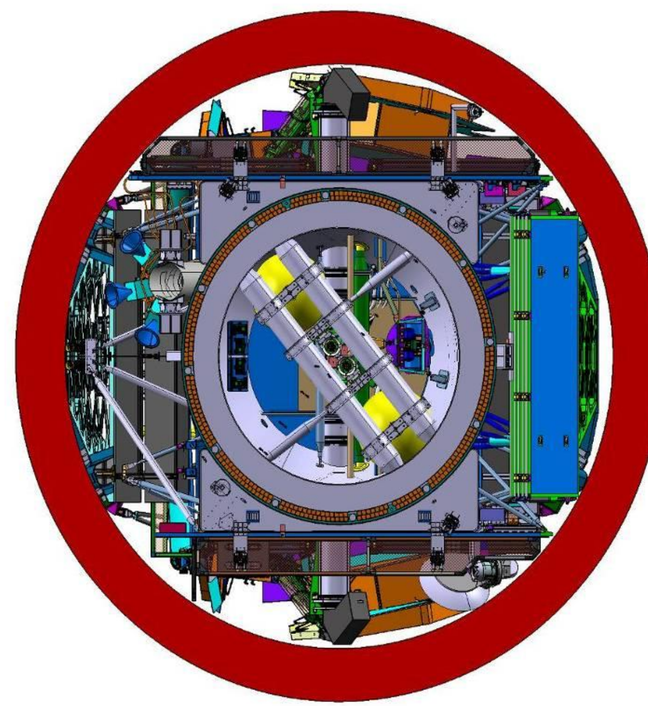


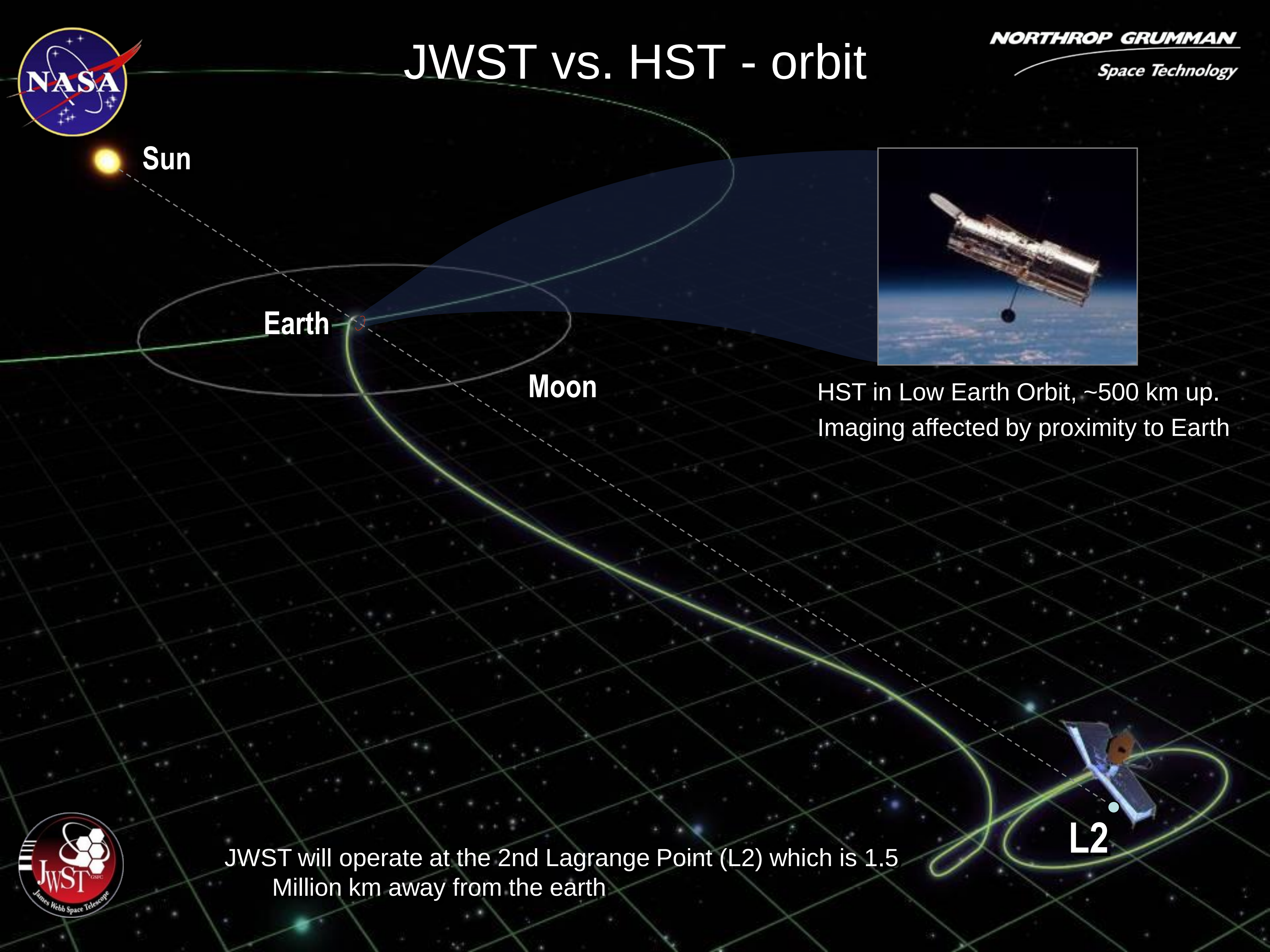
Interferogram with 20 Tilt Fringes

JWST Launch Configuration

Ariane 5 ECA

- JWST is folded and stowed into Arian V with 5 m diameter x 17 m tall fairing
- Launch from Kourou Launch Center (French Guiana) with direct transfer to L2 point.
- Payload launched at ambient temperature with on orbit cooling to 50 K via passive thermal radiators
- JWST payload: 6330 kg




JWST vs. HST - orbit
NORTHROP GRUMMAN
Space Technology
NASA
Sun
Earth
Moon
HST in Low Earth Orbit, ~500 km up.
Imaging affected by proximity to Earth
L2
JWST
James Webb Space Telescope
JWST will operate at the 2nd Lagrange Point (L2) which is 1.5 Million km away from the earth

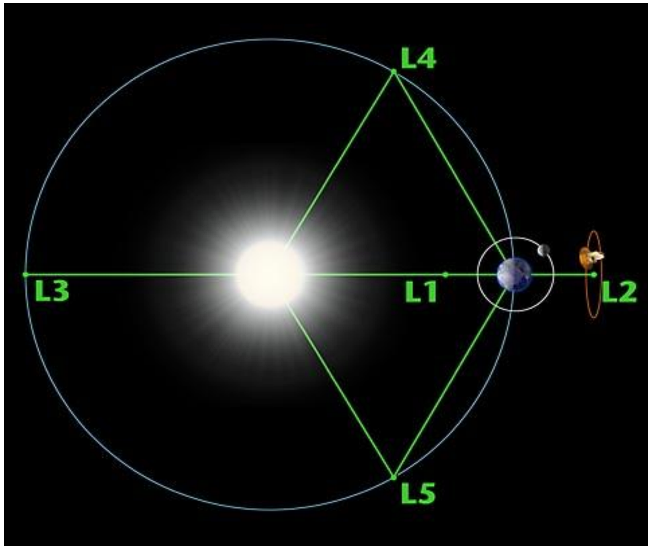
L2 Orbit Enables Passive Cryogenic Operation

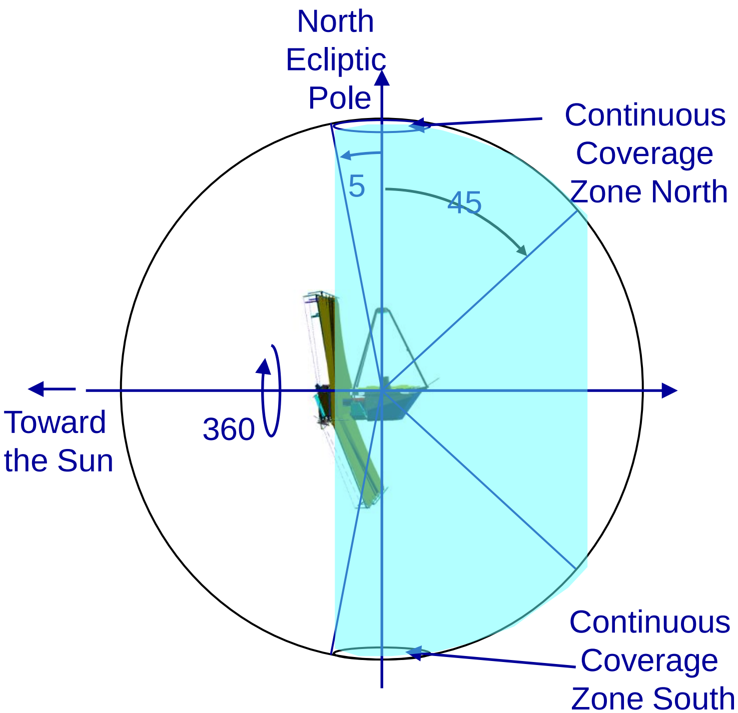
Second Lagrange Point (L2) of Sun-Earth System

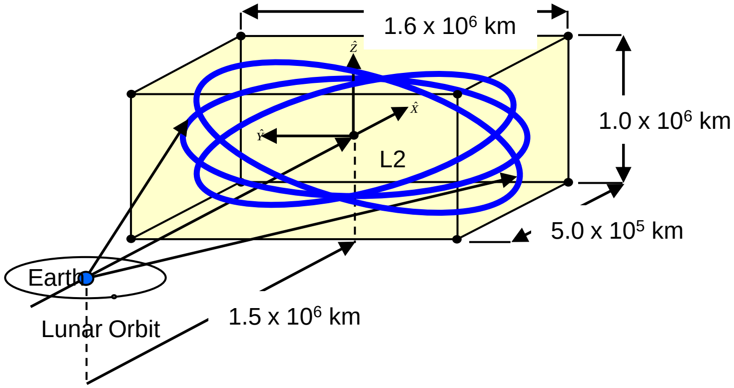
- This point follows the Earth around the Sun

The orbital period about L2 is ~ 6 months

- Station keeping thrusters required to maintain orbit
- Propellant sized for 11 years (delta-v ~ 93





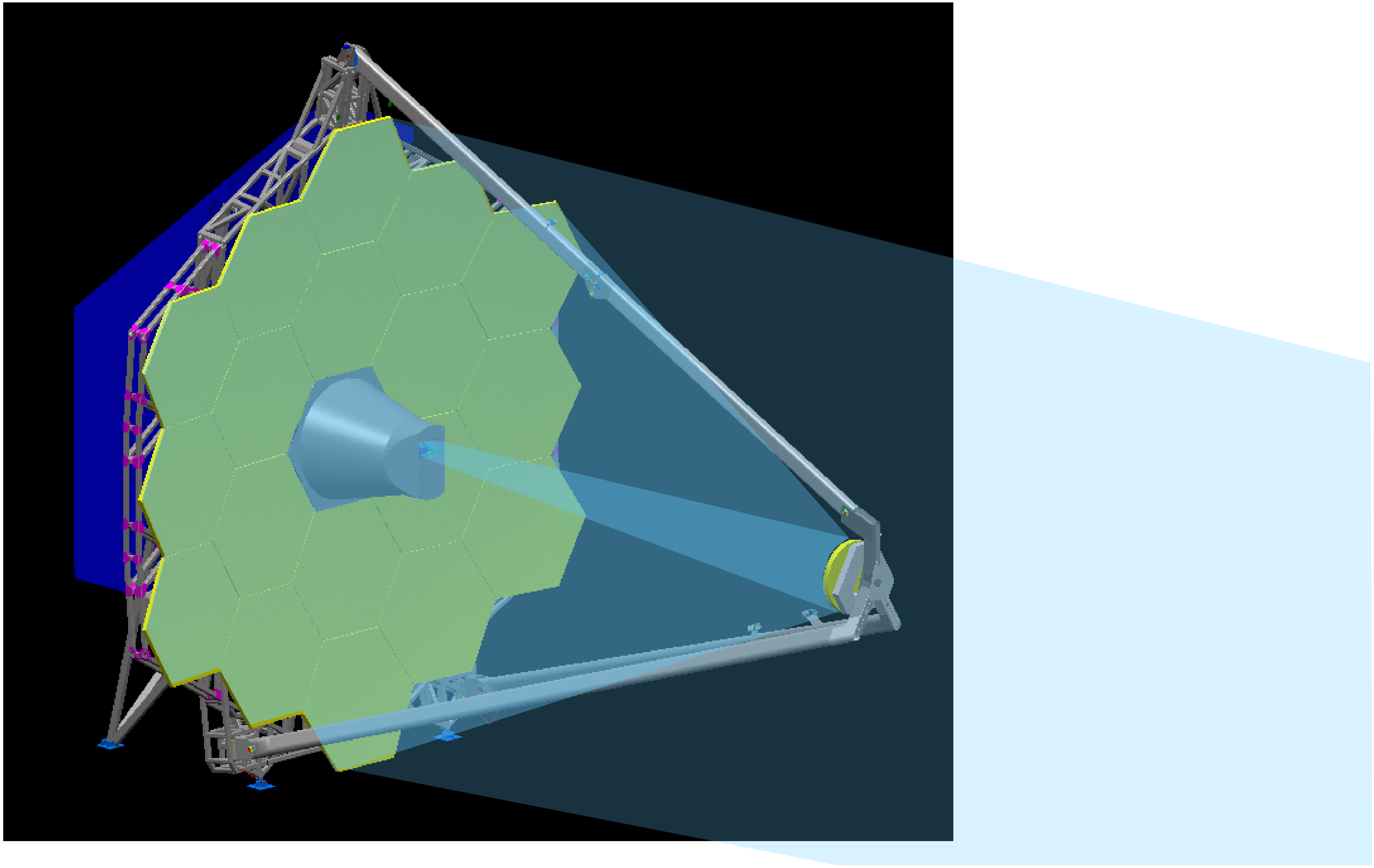


JWST observes whole sky while remaining continuously in shadow of its sunshield

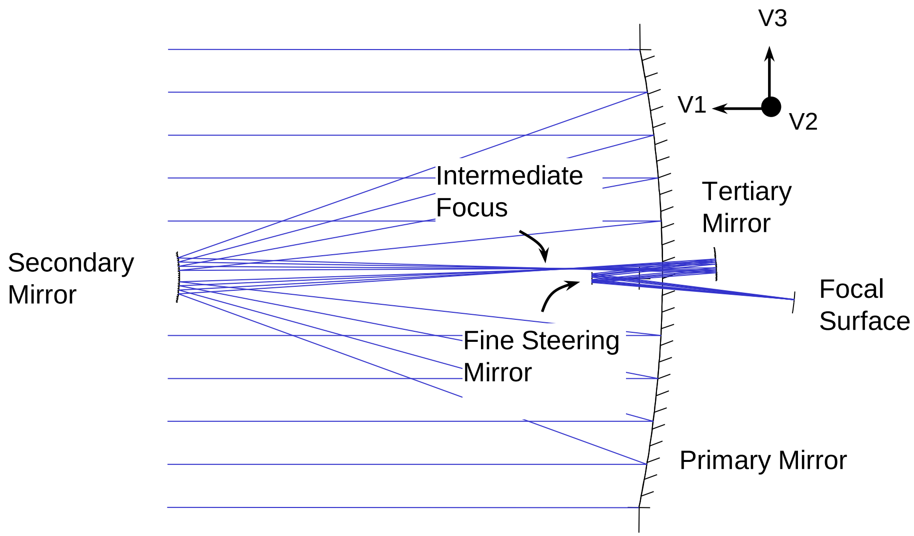
- Field of Regard is annulus covering 35% of the sky
- Whole sky is covered each year

[redacted]

JWST Optical Path

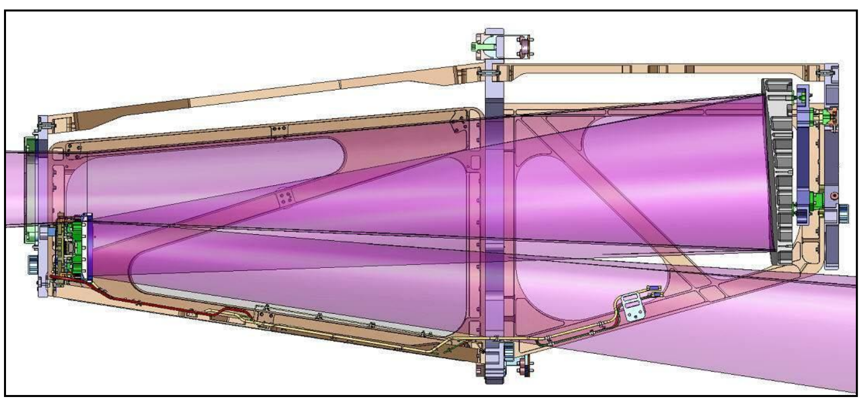


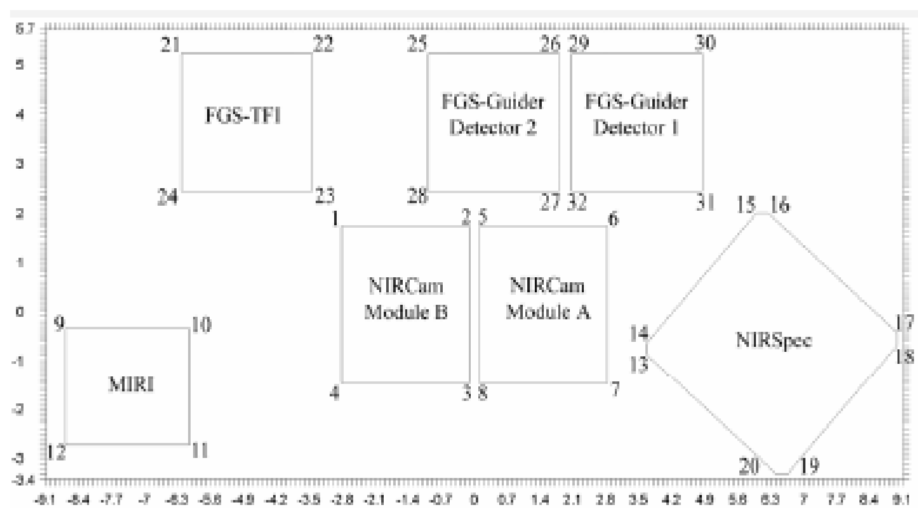
The JWST telescope is a three mirror anastigmat equipped with a fine steering mirror



JWST's is a Three Mirror Anistigmat (TMA)

- Optical design: f/20
- Diameter of PM: 6.6 m
- Effective focal length: 131.4 m
- Clear aperture area: 25 m^2
- Field of view: 18.2 x 9.1 arcmin
- Elliptical f/1.2 Primary Mirror
- Hyperbolic Secondary Mirror creates f/9 intermediate image
- Elliptical Tertiary Mirror images pupil at Fine Steering Mirror
- Transmitted Wavefront Error is 131 nm rms





JWST space vehicle consists of three main elements

Optical Telescope Element (OTE)

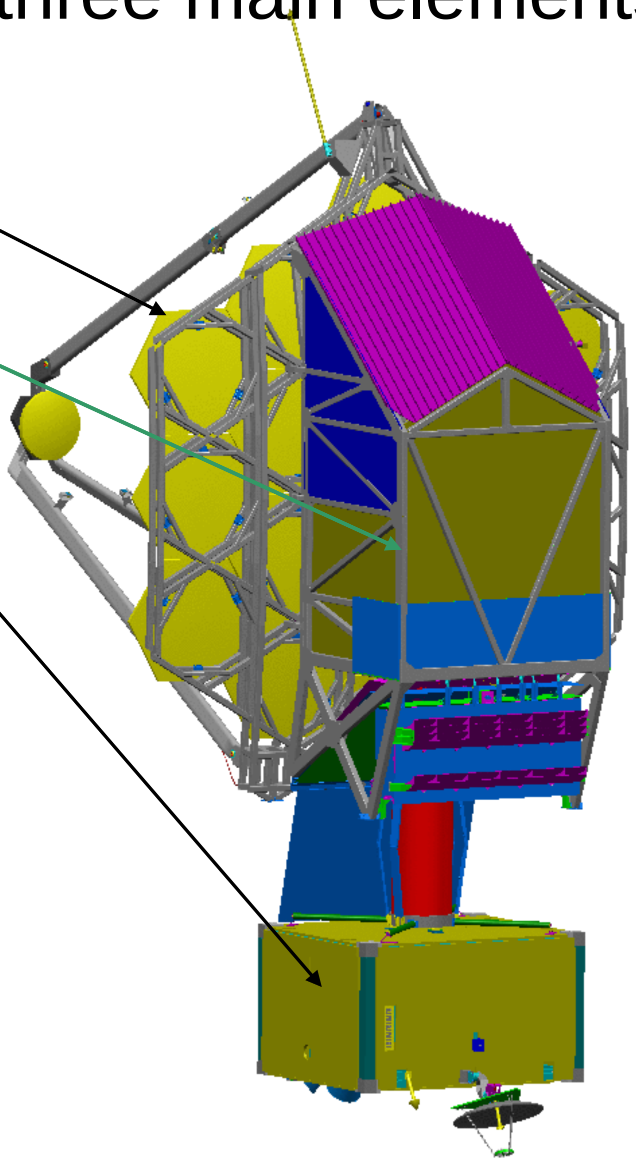
- Collects star light from distant objects

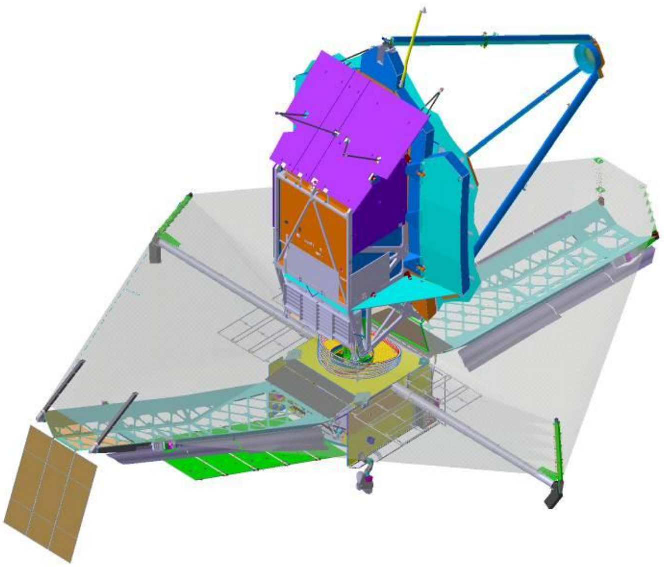
Integrated Science Instrument Module (ISIM)

- Decodes physics information from star light and converts to digital data

Spacecraft

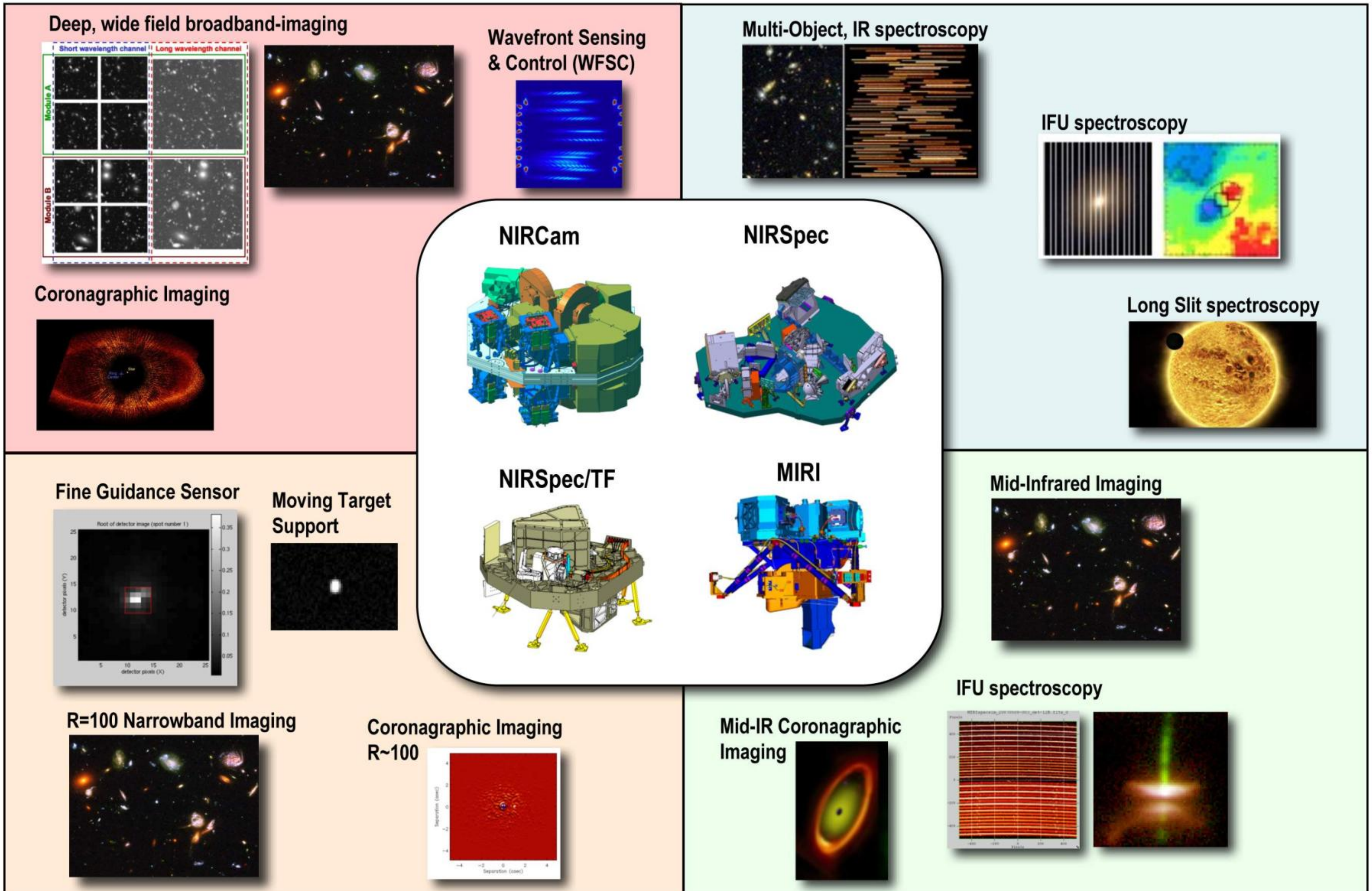
- Attitude control, telecom, power & other support systems



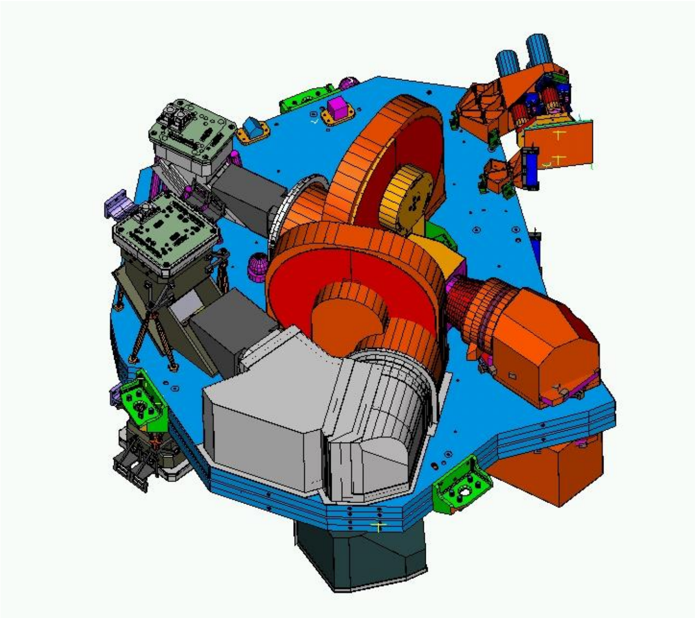


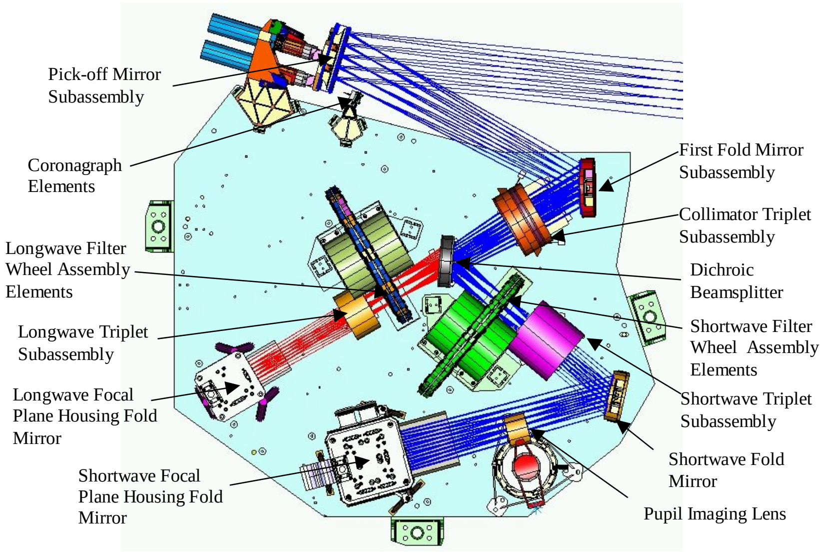
JWST Science Instruments

enable imagery and spectroscopy over the 0.6 – 29 micron spectrum



NIRCam images large portions of the sky identifying primeval galaxy targets for the other instruments





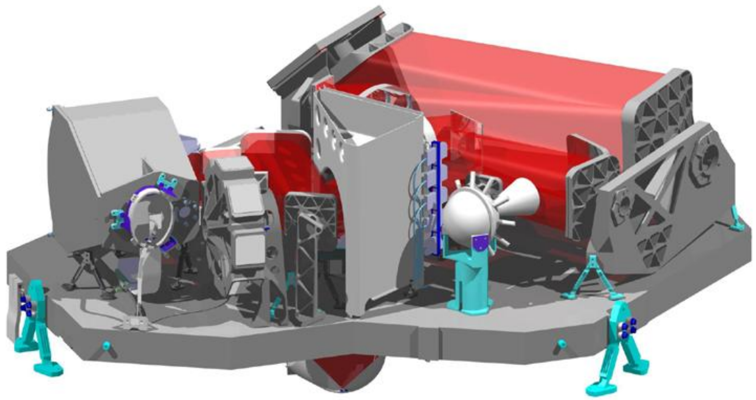
Developed by the University of Arizona with Lockheed Martin ATC

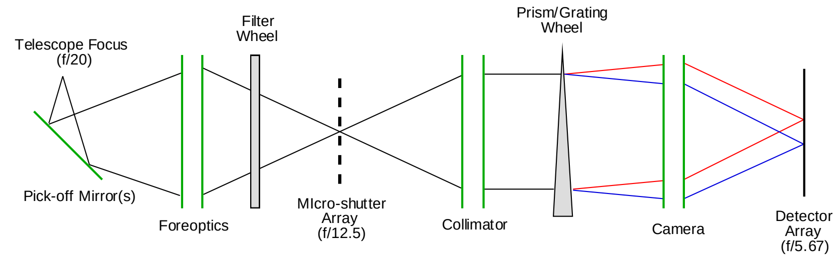
- Operating wavelength: 0.6 – 5.0 microns
- Spectral resolution: 4, 10, 100
- Field of view: 2.2 x 4.4 arc minutes
- Angular resolution (1 pixel): 32 mas < 2.3 microns, 65 mas > 2.4 microns
- Detector type: HgCdTe, 2048 x 2048 pixel format, 10 detectors, 40 K passive cooling
- Refractive optics, Beryllium structure

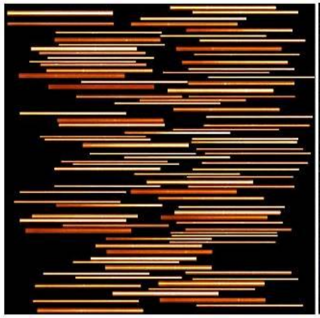
Supports OTE wavefront sensing

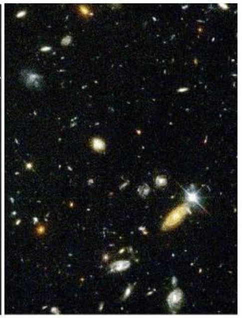
NIRCam ETU in integration now

NIRSpec obtains spectra of 100 galaxies per exposure



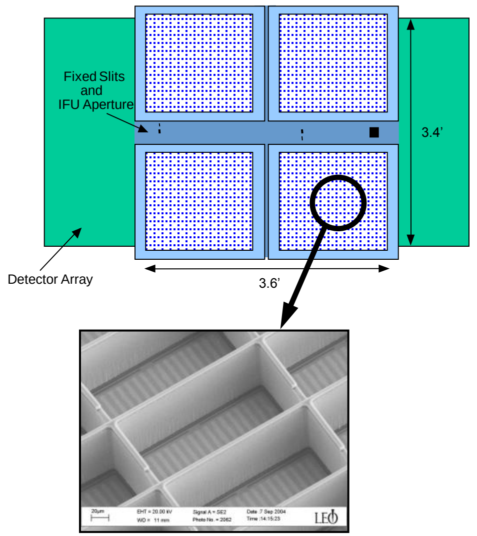






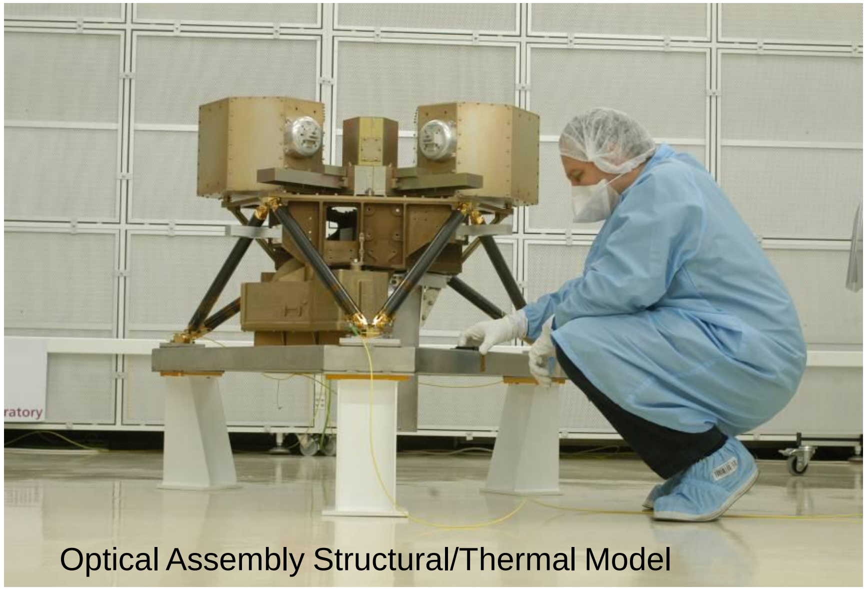
Developed by the European Space Technology Center (ESTEC) with Astrium GmbH and Goddard Space Flight Ctr

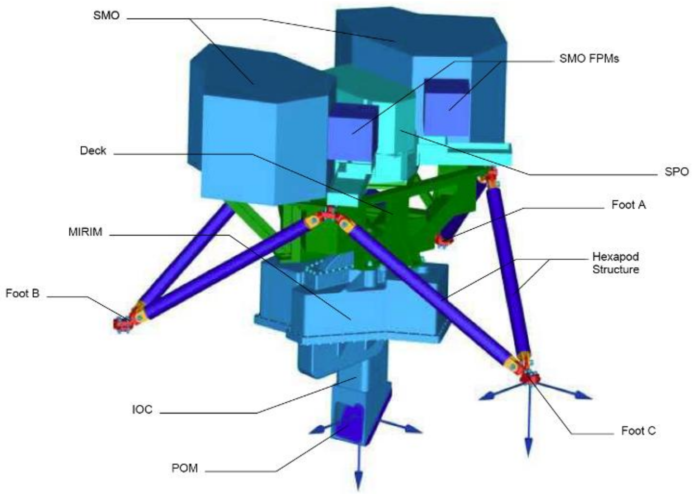
- Operating wavelength: 0.6 – 5.0 microns
- Spectral resolution: 100, 1000, 3000
- Field of view: 3.4 x 3.4 arc minutes
    - Aperture control: programmable micro-shutters, 250,000 pixels
    - Angular resolution: shutter open area 203 x 463 mas, pitch 267 x 528 mas
- Detector type: HgCdTe, 2048 x 2048 pixel format, 2 detectors, 37 K passive cooling
- Reflective optics, SiC structure and optics



ETU Testing & FM Integration Underway Now

MIRI studies galaxy evolution


Optical Assembly Structural/Thermal Model

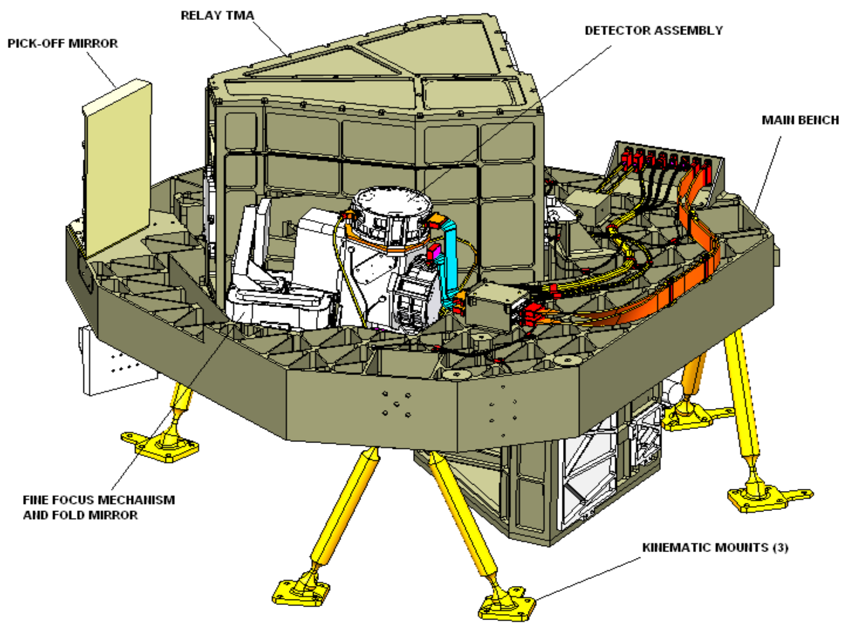


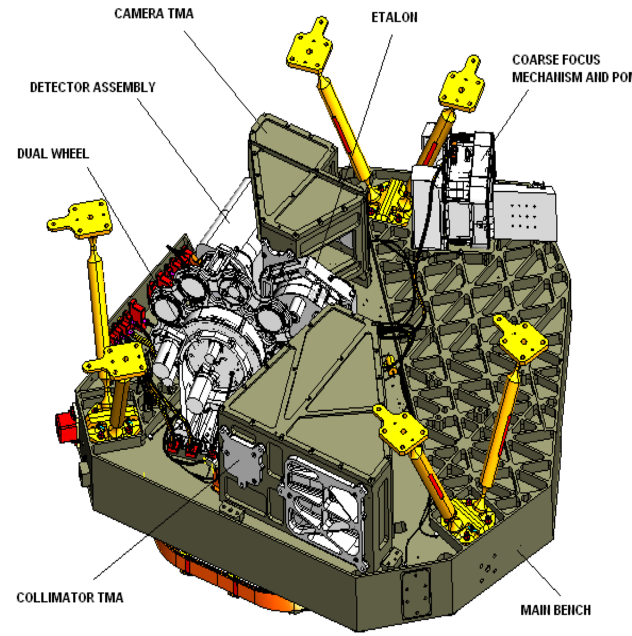
Developed by the United Kingdom Advanced Technology Center and JPL

- Operating wavelength: 5 - 29 microns
- Spectral resolution: 5, 100, 2000
- Field of view: 1.9 x 1.4 arc minutes broad-band imagery
  - R100 spectroscopy 5 x 0.2 arc sec slit
  - R2000 spectroscopy 3.5 x 3.5 and 7 x 7 arc sec integral field units
- Detector type: Si:As, 1024 x 1024 pixel format, 3 detectors, 7 K cryo-cooler
- Reflective optics, Aluminum structure and optics

ETU Testing Completed Dec 08
Flight Model in Integration Now

FGS provides imagery for telescope pointing control & imaging spectroscopy to reveal primeval galaxies and extra-solar planets



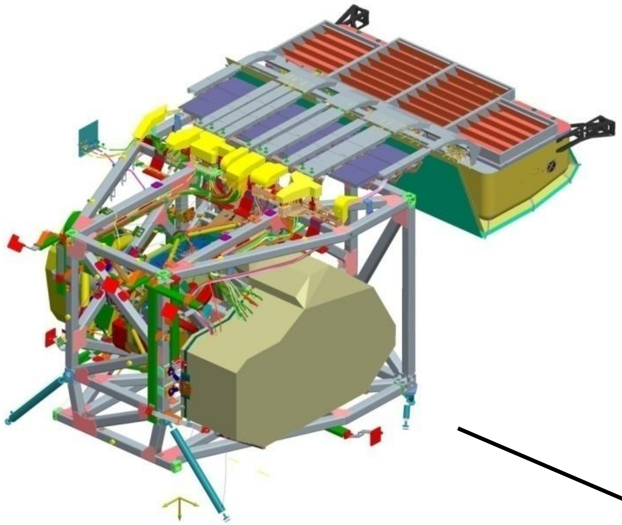


Developed by the Canadian Space Agency with ComDev

- Operating wavelength: 0.8 – 4.8 microns
- Spectral resolution: Broad-band guider and R=100 science imagery
- Field of view: 2.3 x 2.3 arc minutes
  - R=100 imagery with Fabry-Perot tunable filter and coronagraph
- Angular resolution (1 pixel): 68 mas
- Detector type: HgCdTe, 2048 x 2048 pixel format, 3 detectors, 40 K passive cooling
- Reflective optics, Aluminum structure and optics

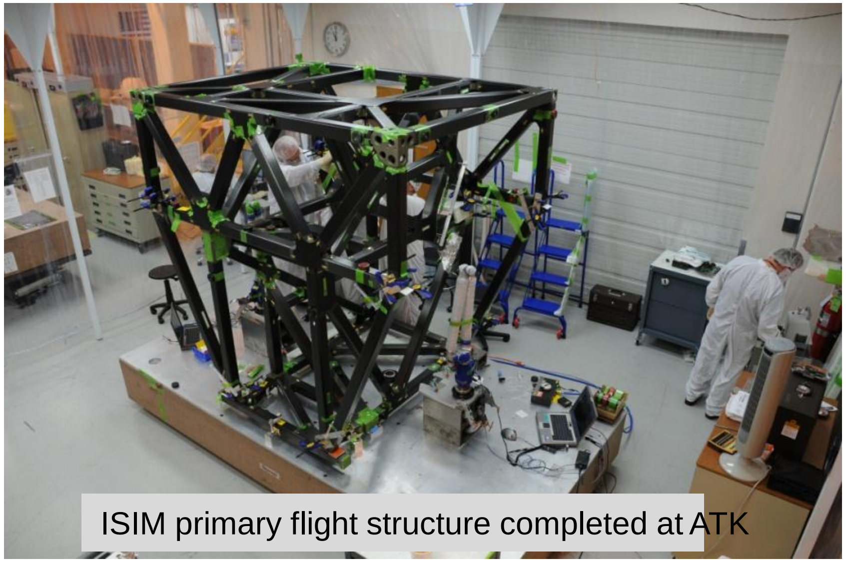
FGS ETU in Test Now

All Science Instruments integrate into ISIM

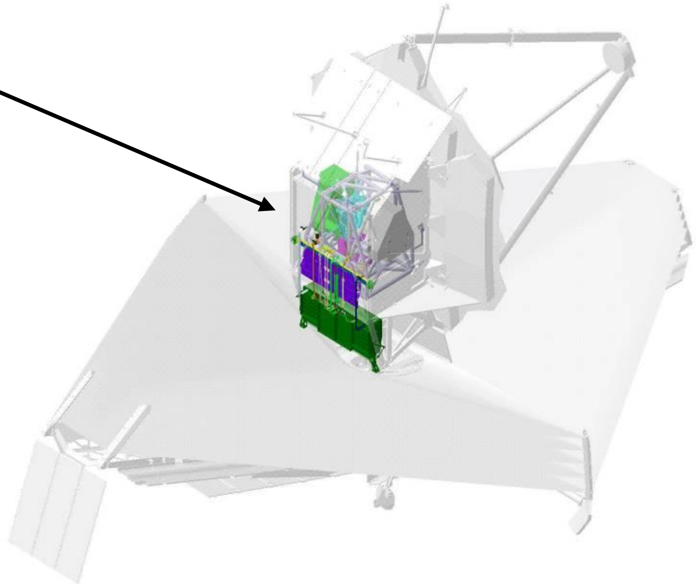


Integrated Science Instrument Module (ISIM) contains:

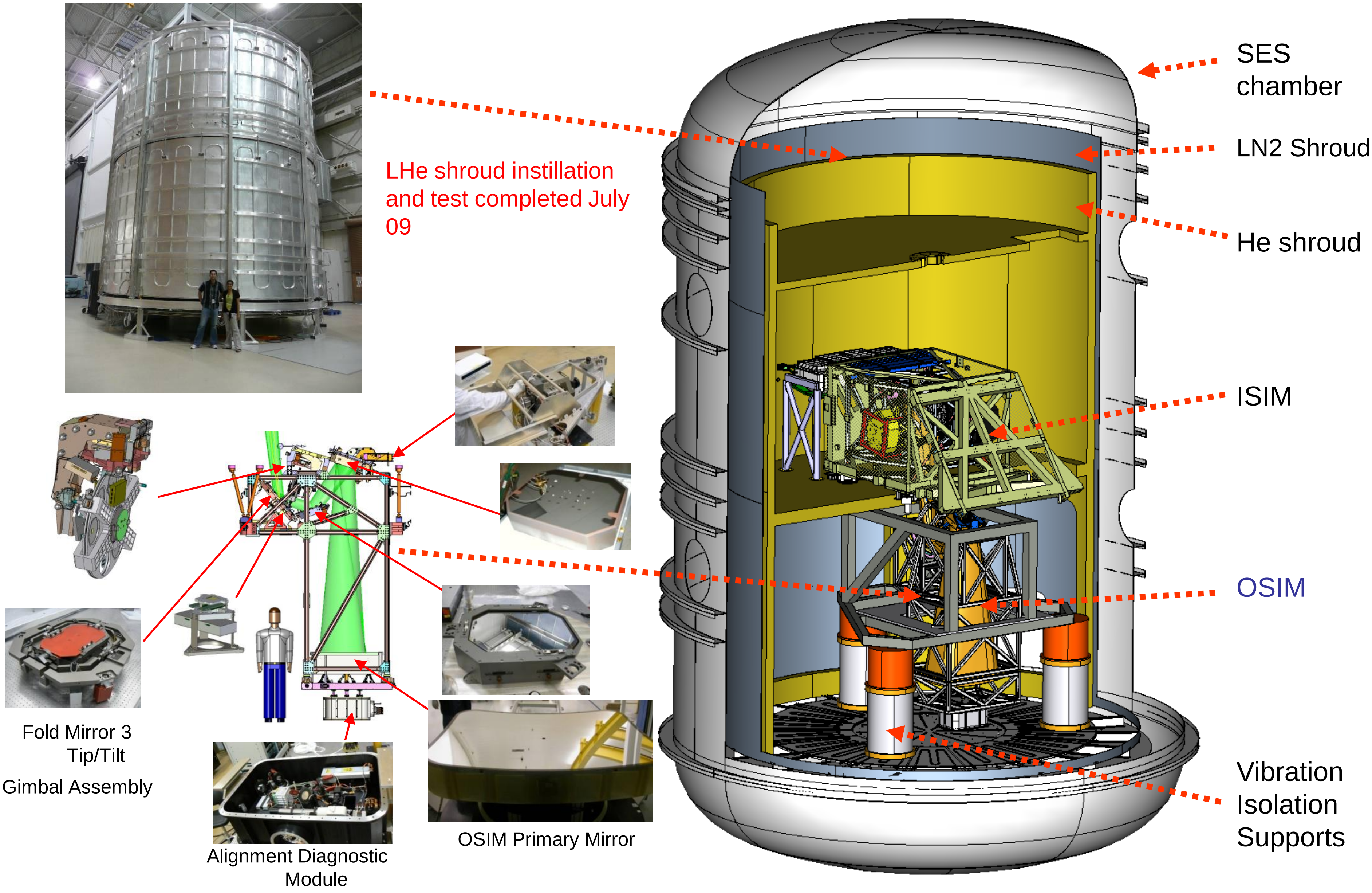
- Four science instruments
- Command and data handling system
- Flight software system
- Passive cryogenic thermal control system
- Optical metering structure system
- Science instrument control electronics
- Electrical harness system



ISIM primary flight structure completed at ATK

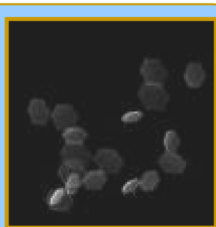


ISIM will be tested in the GSFC SES chamber using an Optical Telescope Simulator (OSIM)

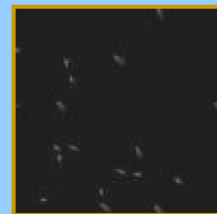


Deployed Telescope Phasing

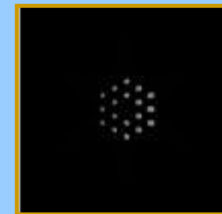
First Image



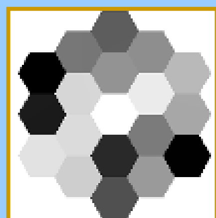
Secondary Mirror Focus Sweep

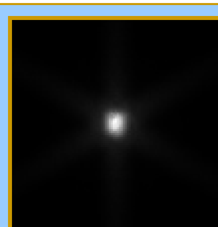


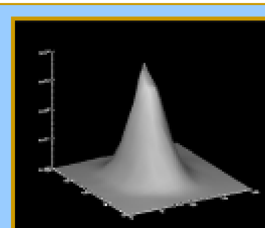
Segment ID and Image Array



Global Alignment

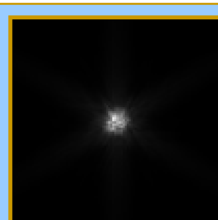


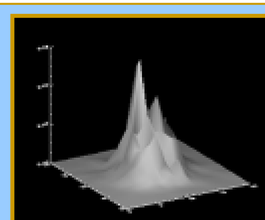




Segment wave front error <200nm and segment-to-segment piston <100µm rms after Global Alignment

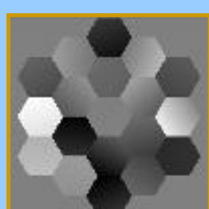
Coarse Phasing (Fine Guiding)

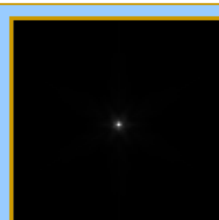


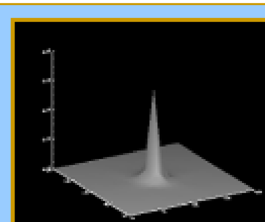


PM wave front error < 1000 nm rms after Coarse Phasing

Fine Phasing (SP & MIMF)



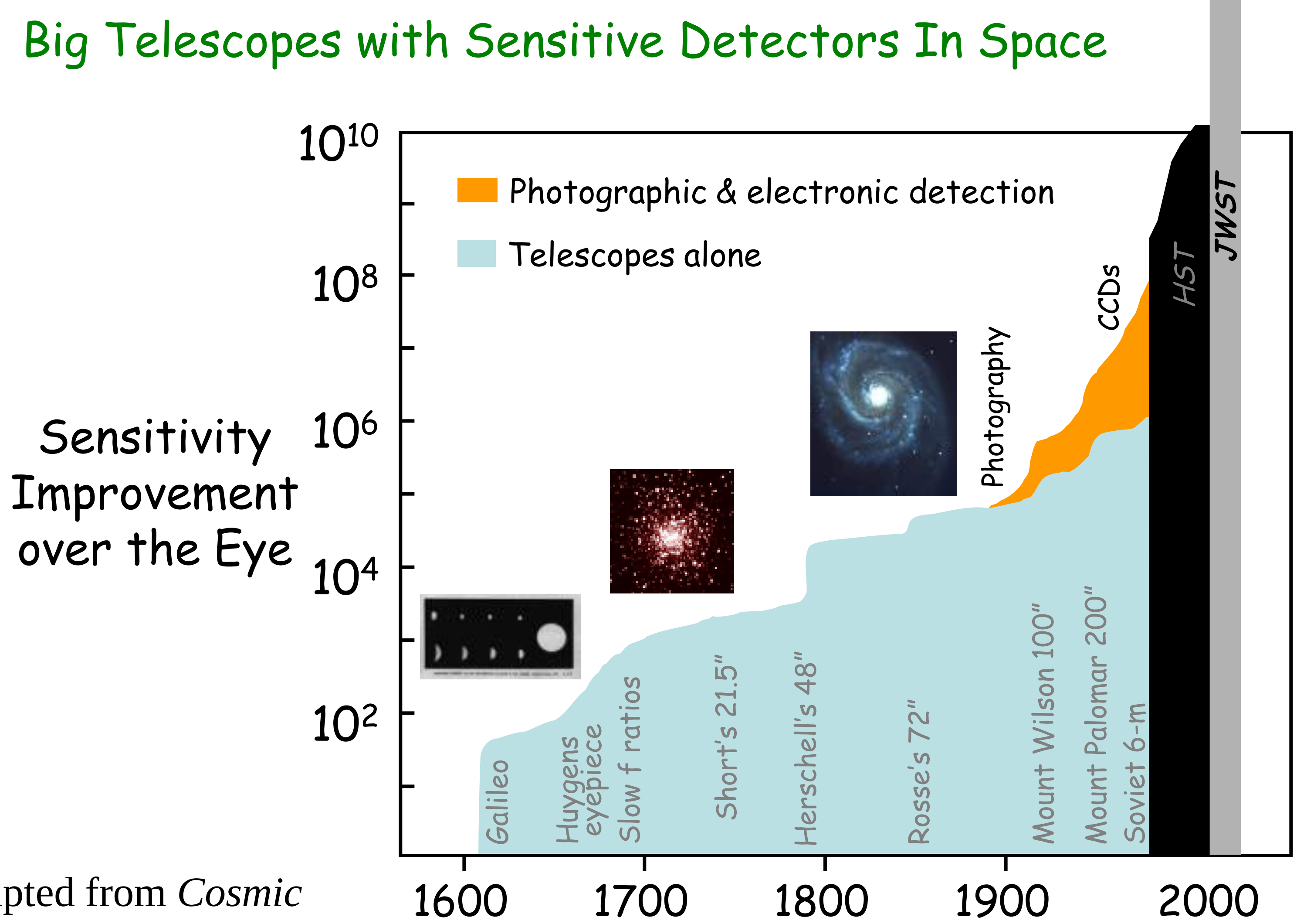




OTE wave front error < 131 nm rms after Fine Phasing; stability > 14 days

Processes have been demonstrated on the Test Bed Telescope as part of TRL-6 development

How to win at Astronomy
Aperture = Sensitivity



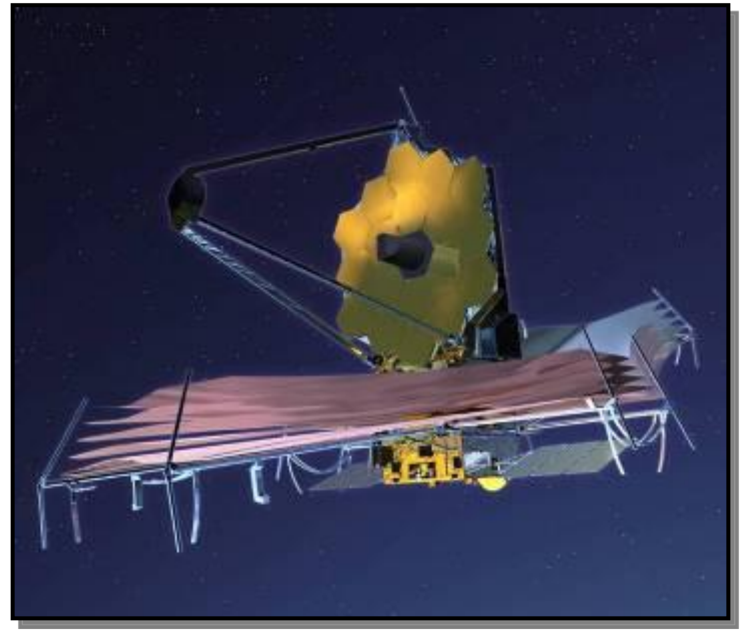
Adapted from *Cosmic Discovery*, M. Harwit

JWST Expands on HST Capabilities

HST: 2.4 m diameter Primary Mirror

Room Temperature

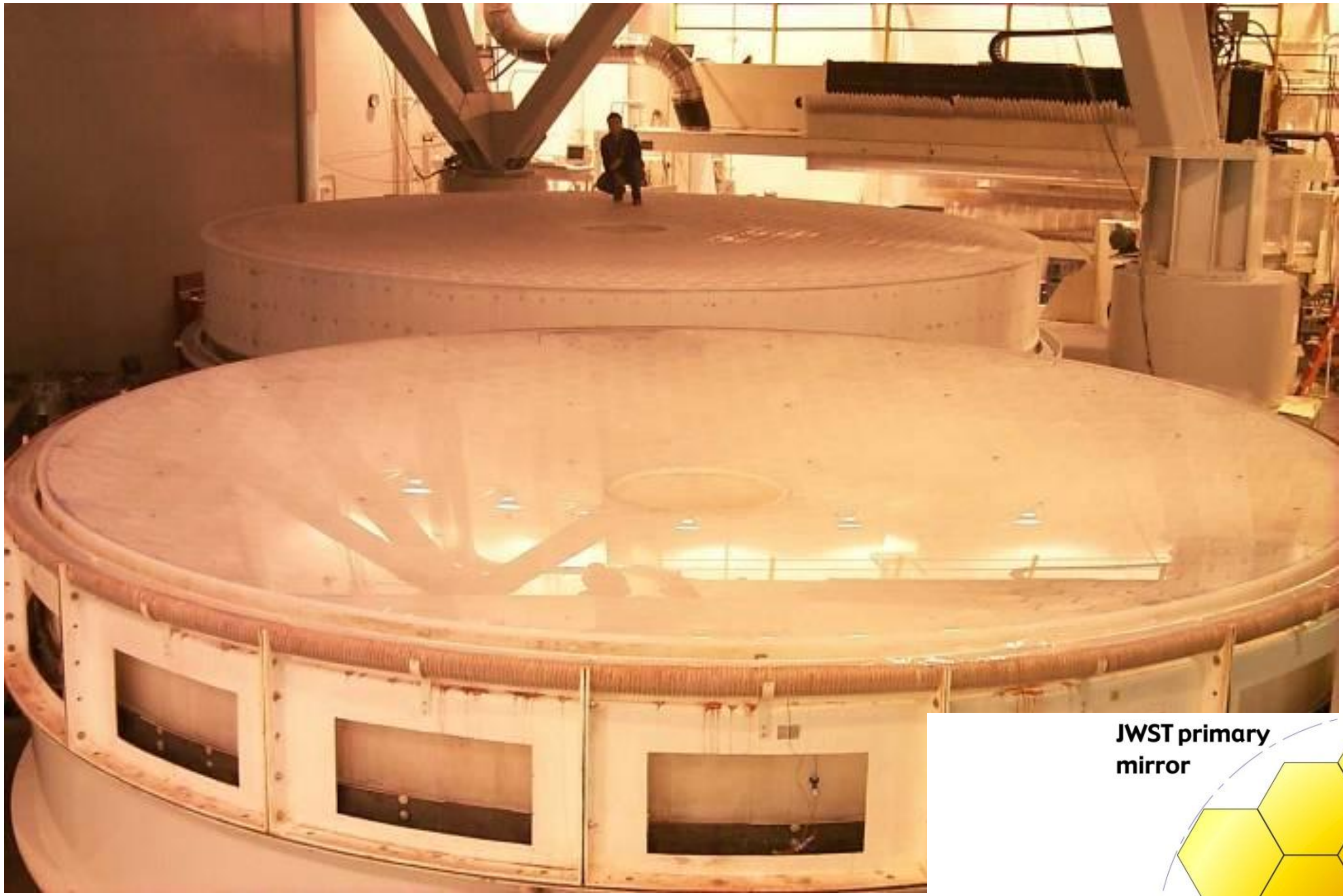
JWST: 6.5 m diameter Primary Mirror

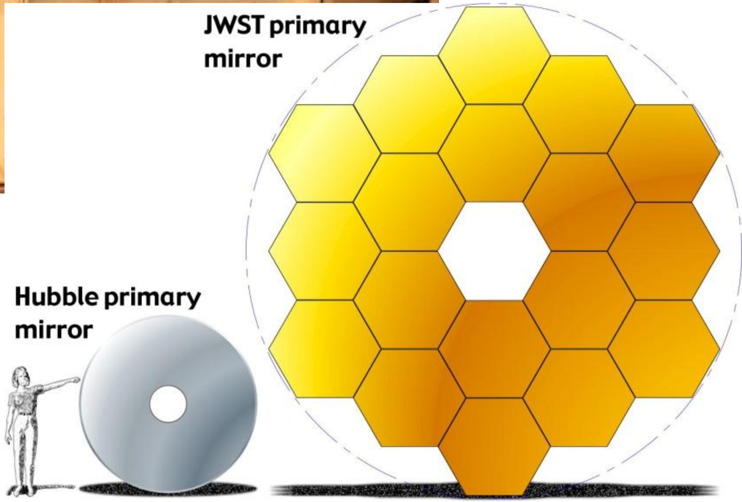


< 50 K (~ -223 C or -370 F)

- **JWST has 7x the light gathering capability of the Hubble Space Telescope**
- **JWST operates in extreme cold to enable sensitive infrared light collection**
- **JWST has same angular resolution in the near-IR as HST in visible**

How big is JWST?





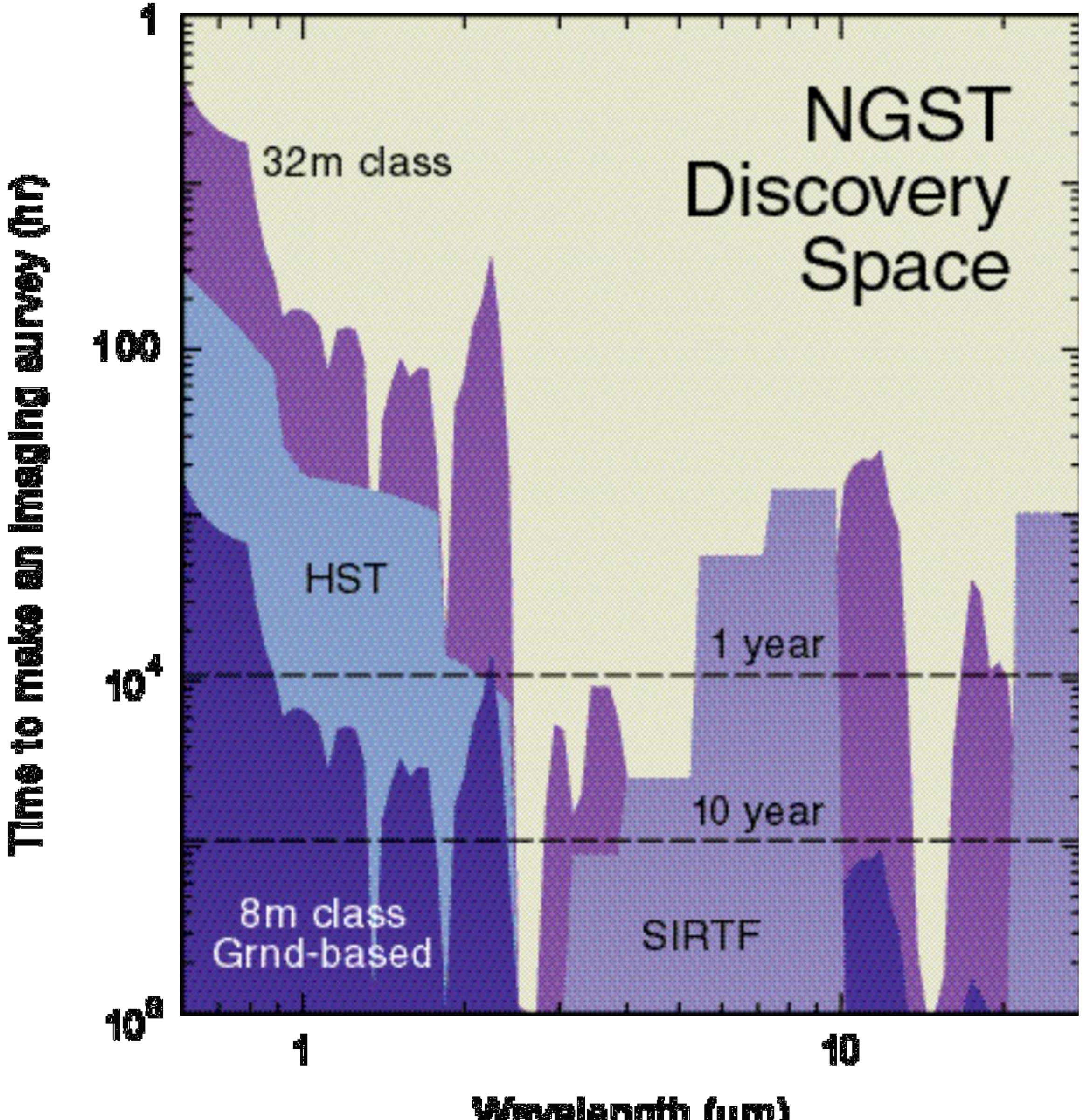
Full Scale JWST Mockup

21st National Space Symposium, Colorado Springs, The Space Foundation

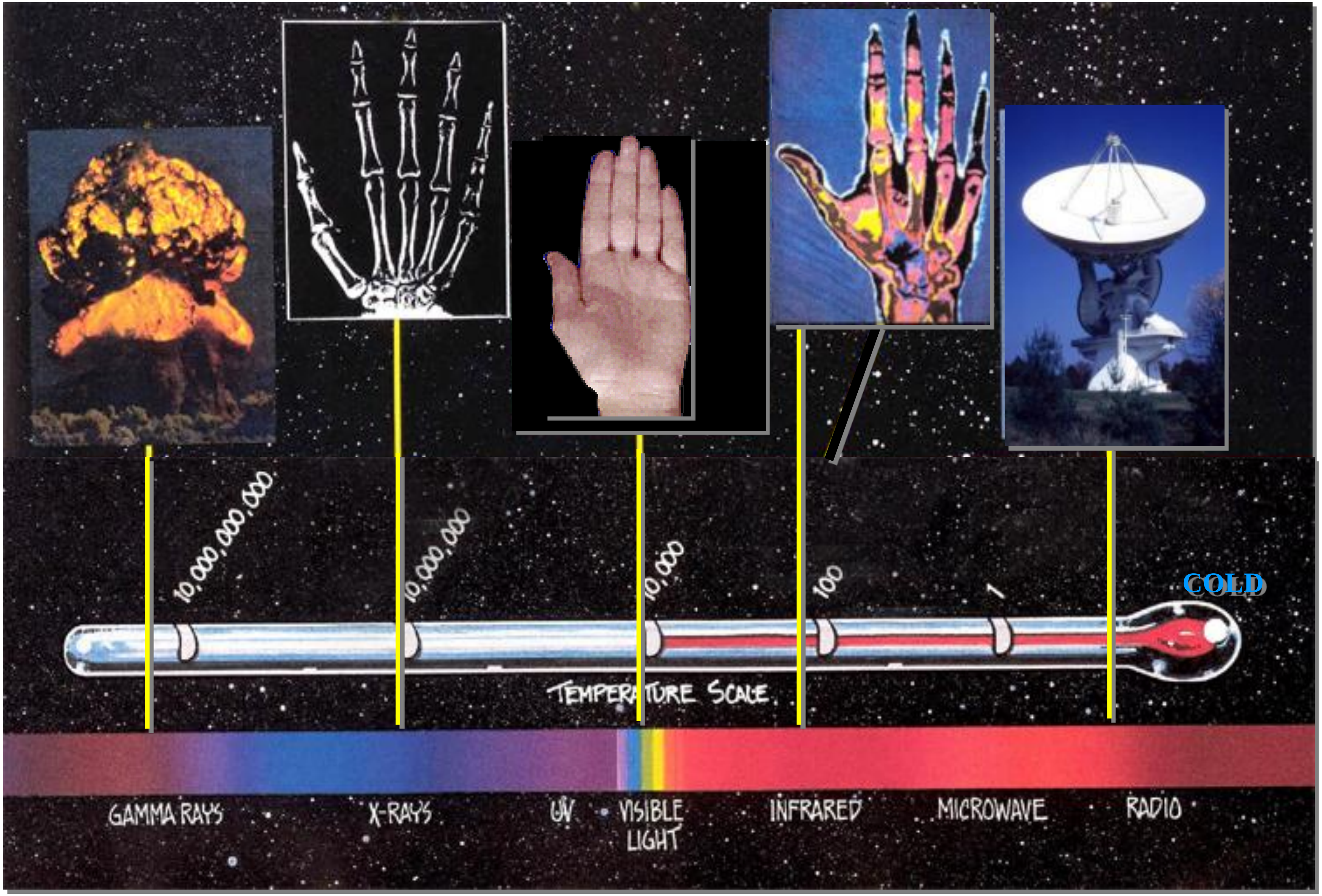
Full Scale JWST Mockup

21st National Space Symposium, Colorado Springs, The Space Foundation

Why go to Space – Wavelength Coverage



Infrared Light



Why Infrared ?

JWST Science Theme #1

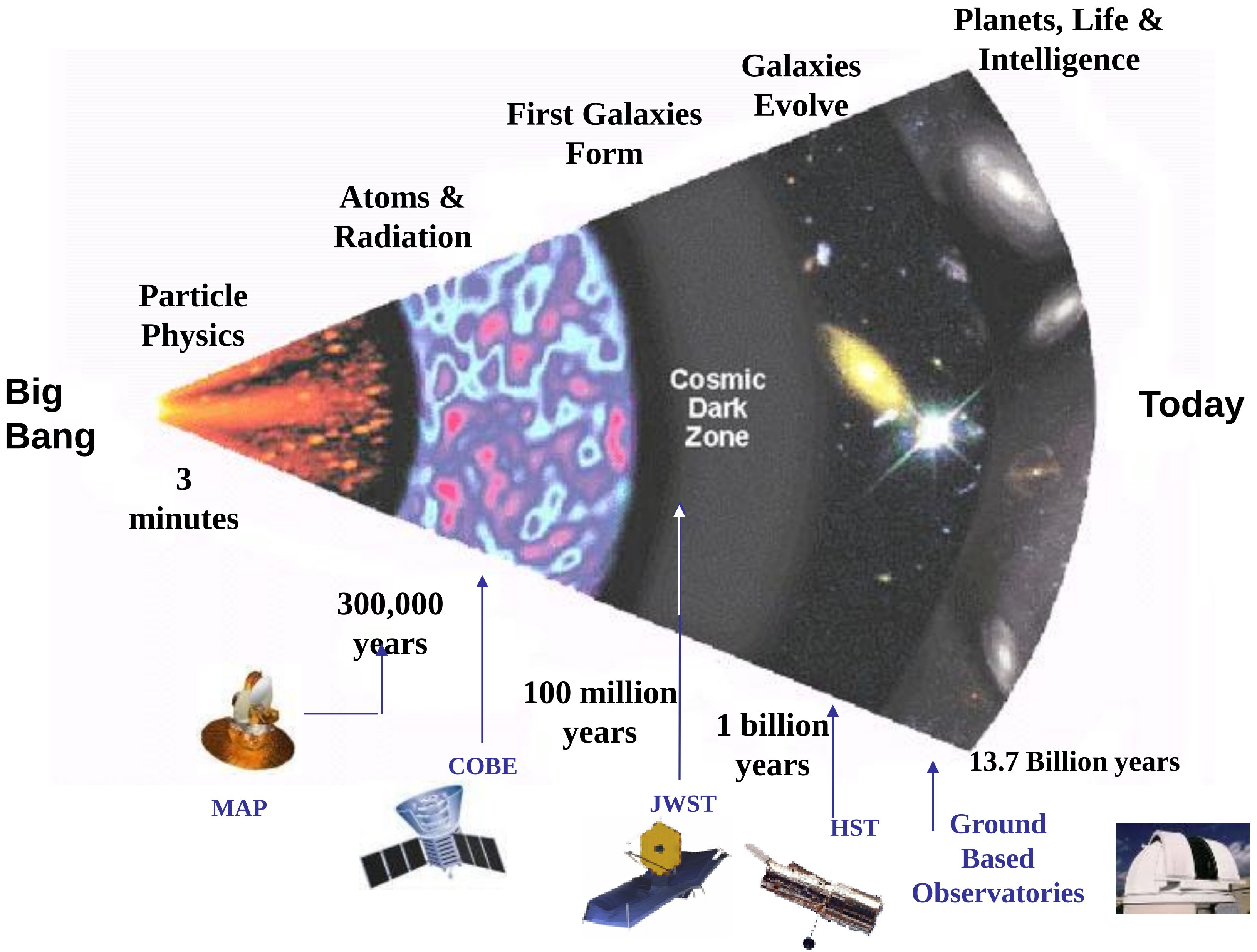
End of the dark ages: first light and reionization

What are the first luminous objects?
What are the first galaxies?
How did black holes form and interact with their host galaxies?
When did re-ionization of the inter-galactic medium occur?
What caused the re-ionization?

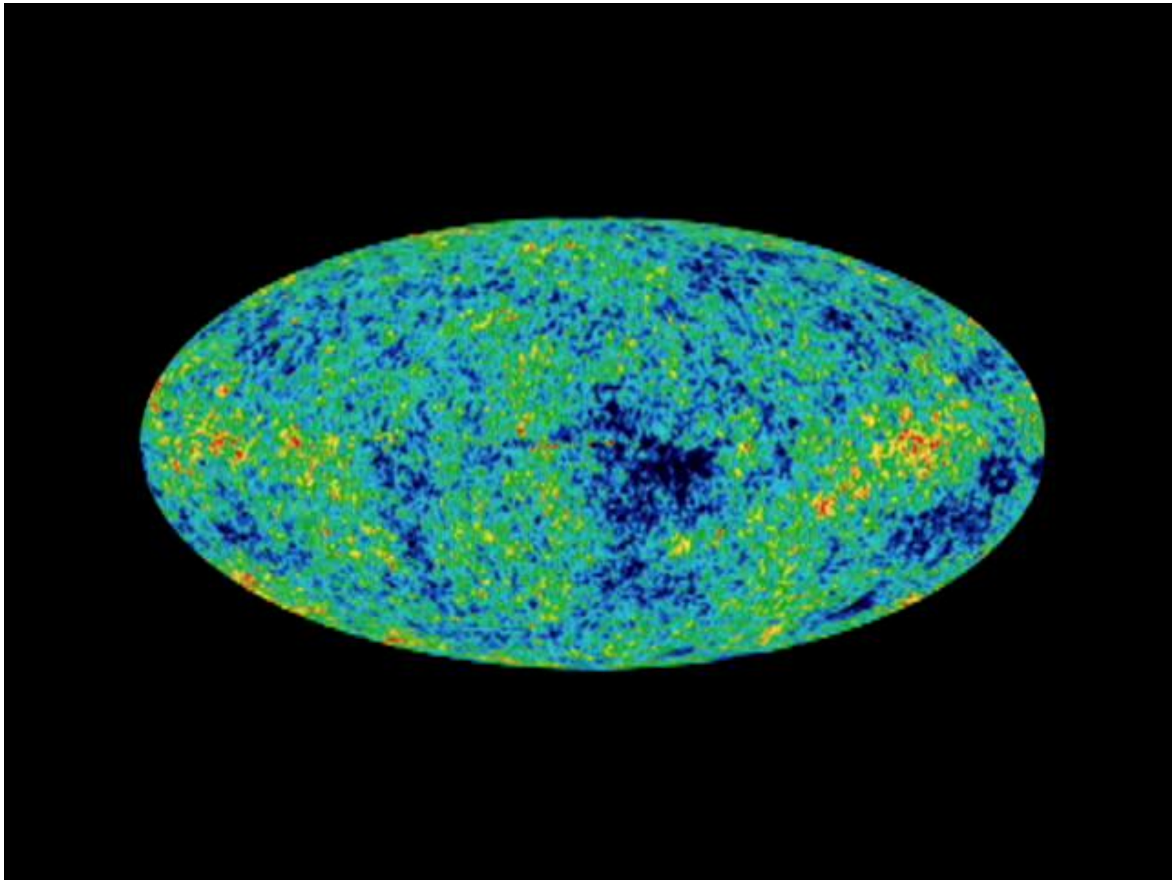
… to identify the first luminous sources to form and to determine the ionization history of the early universe.

Hubble Ultra Deep Field

A Brief History of Time

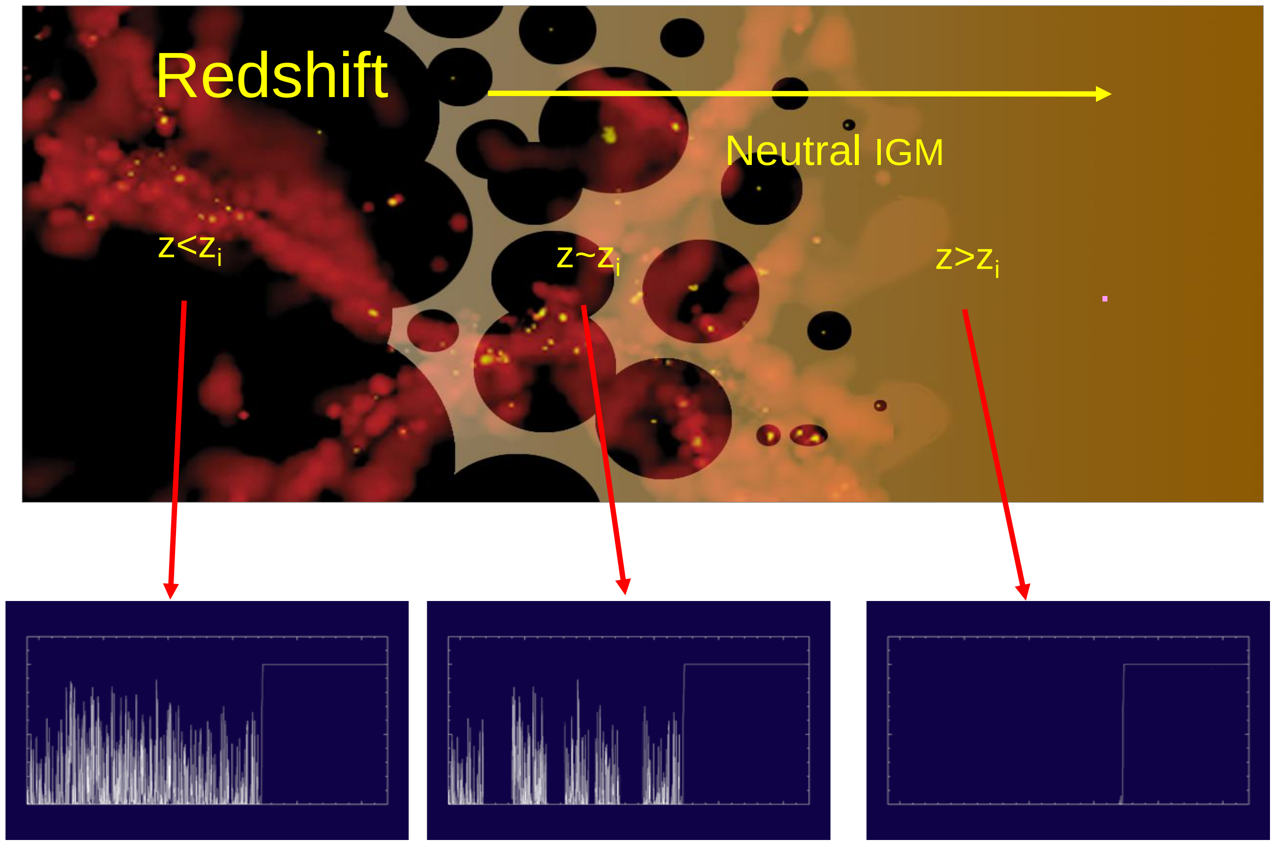


History of Time?



WMAP Results		
Parameter	WMAP Value	What is it ?
Ototal	1.02 +/- 0.02	Total Density
Ω_{lambda}	0.73 +/- 0.04	Dark Energy
Ω_{matter}	0.27 +/- 0.04	Matter Density
Ω_{baryon}	0.044 +/- 0.004	Baryon Density
H_o	71 +/- 4 km/s/Mpc	Hubble Constant
t_o	13.7 +/- 0.2 Gyr	Age of the universe

First Light: Observing Reionization Edge



Lyman Forest Absorption **Patchy Absorption** **Black Gunn-Peterson trough**

When and how did reionization occur?

Re-ionization happened at z>6 or 1 billion years after Big Bang.

- WMAP says maybe twice?

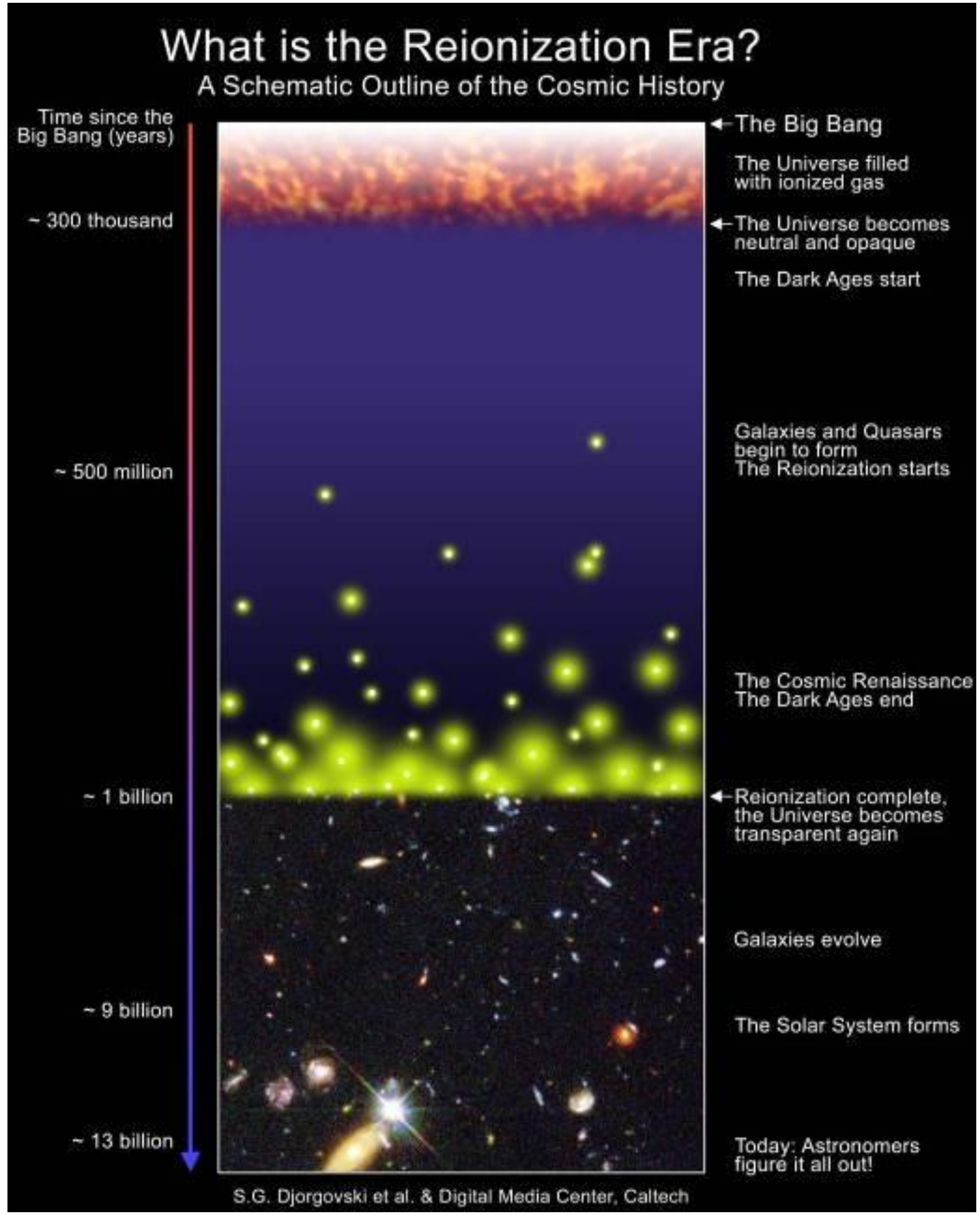
Probably galaxies, maybe quasar contribution

Key Enabling Design Requirments:

- Deep near-infrared imaging survey (1nJy)
- Near-IR multi-object spectroscopy
- Mid-IR photometry and spectroscopy

JWST Observations:

- Spectra of the most distant quasars
- Spectra of faint galaxies



End of the dark ages: first light and reionization

First galaxies are small & faint

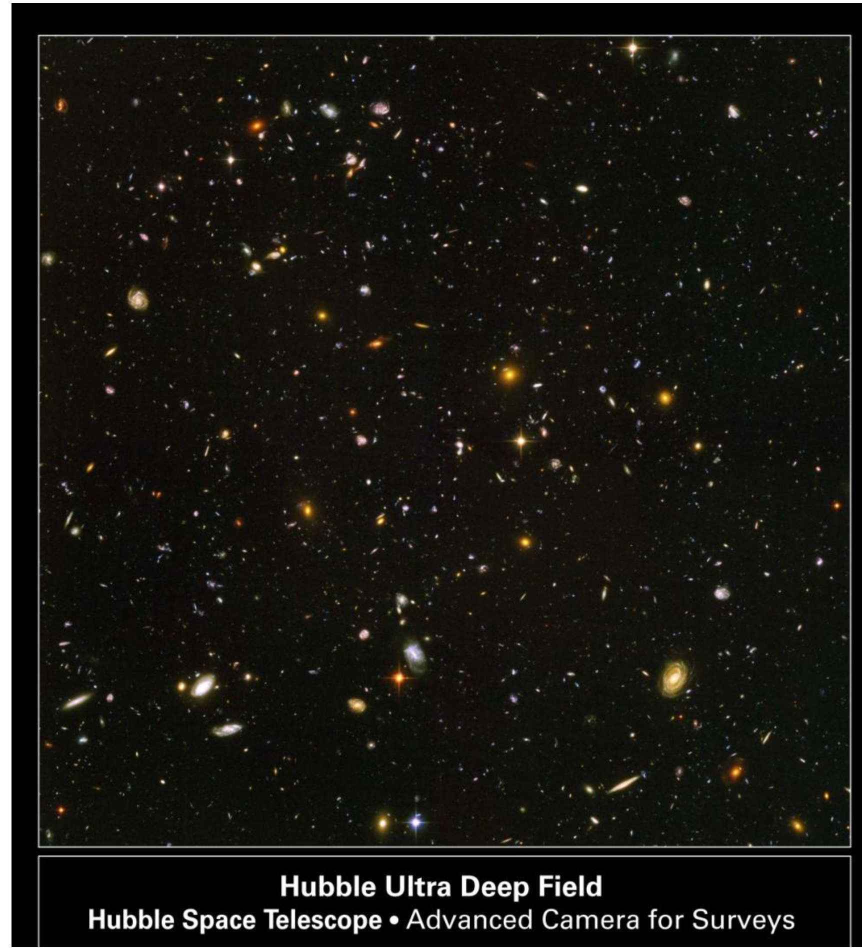
Light is redshifted into infrared.

Low-metallicity, massive stars.

- SNe! GRBs!

JWST Observations

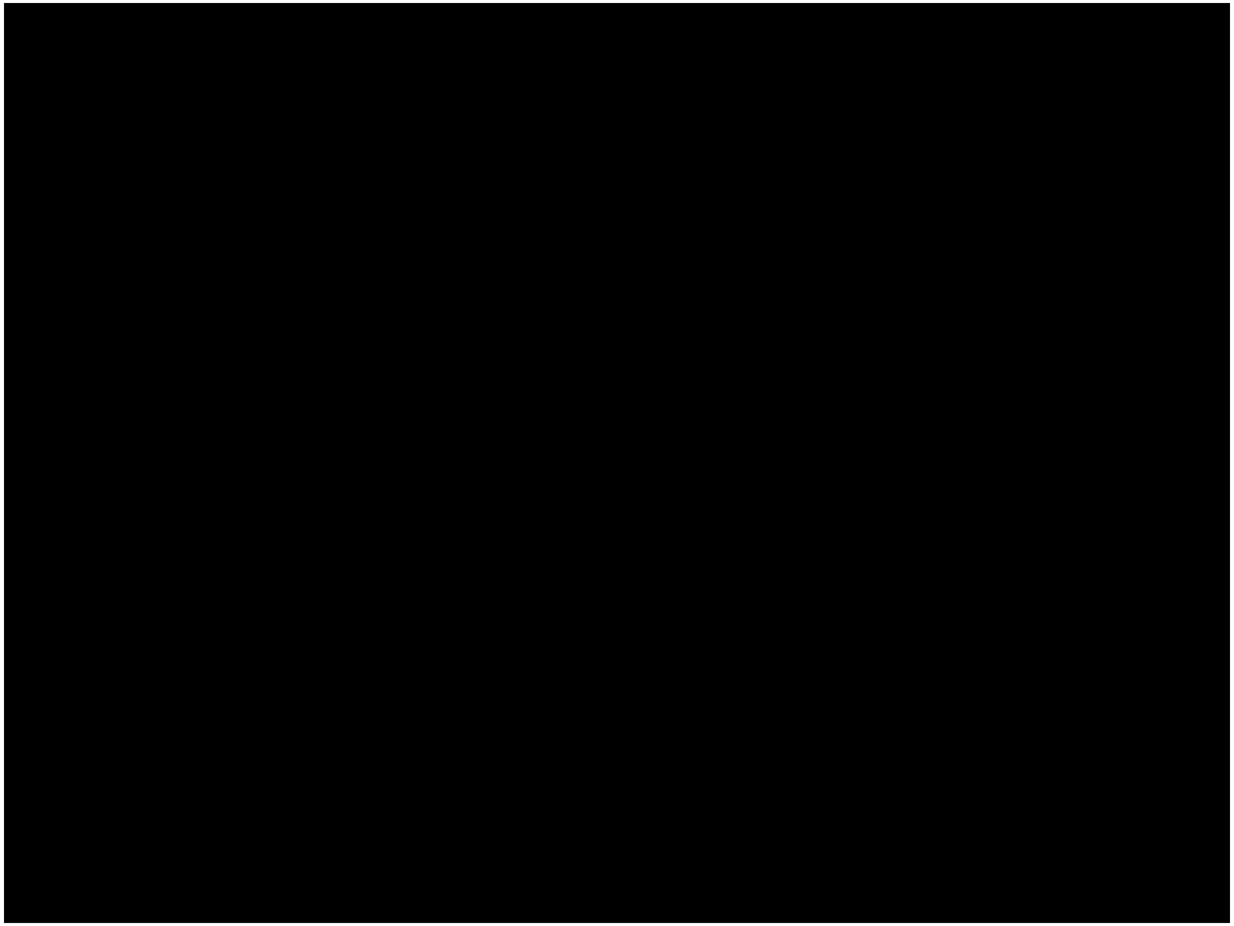
- Ultra-Deep NIR survey (1.4 nJy), spectroscopic & Mid-IR confirmation.



First Light

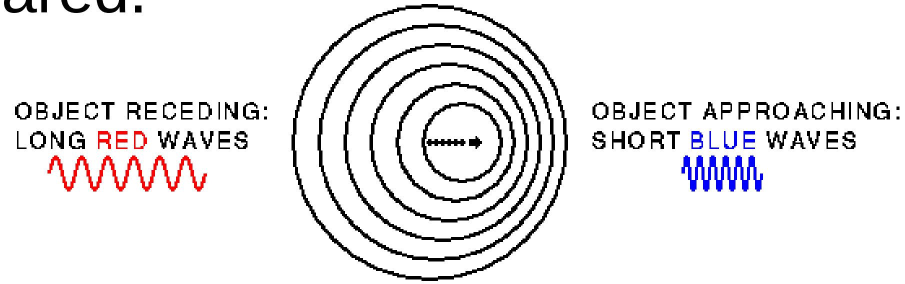
What did the first stars galaxies to form look like?

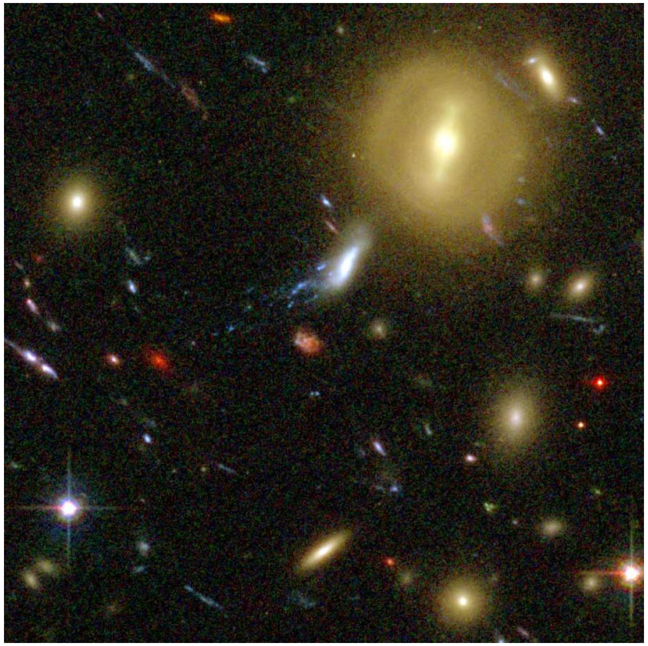
We don’t know, but models suggest first stars were very massive!

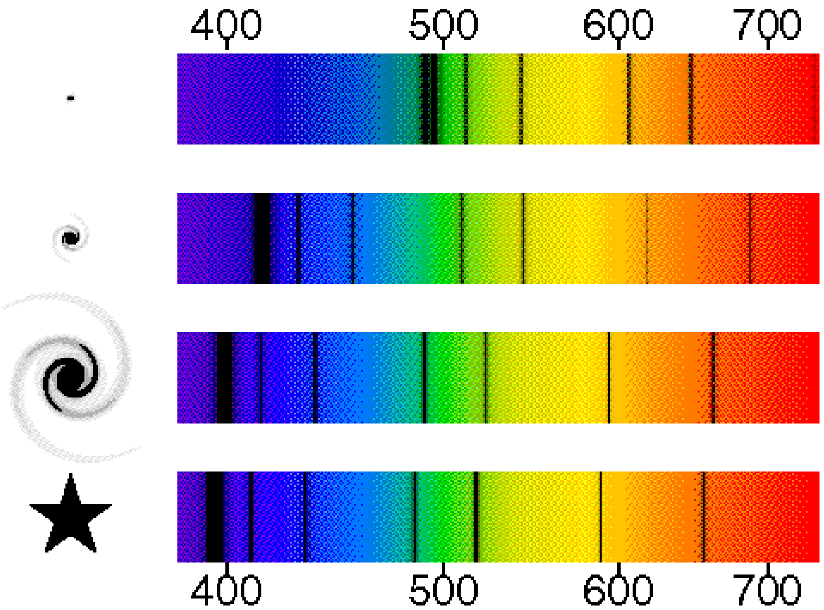


Infrared Light

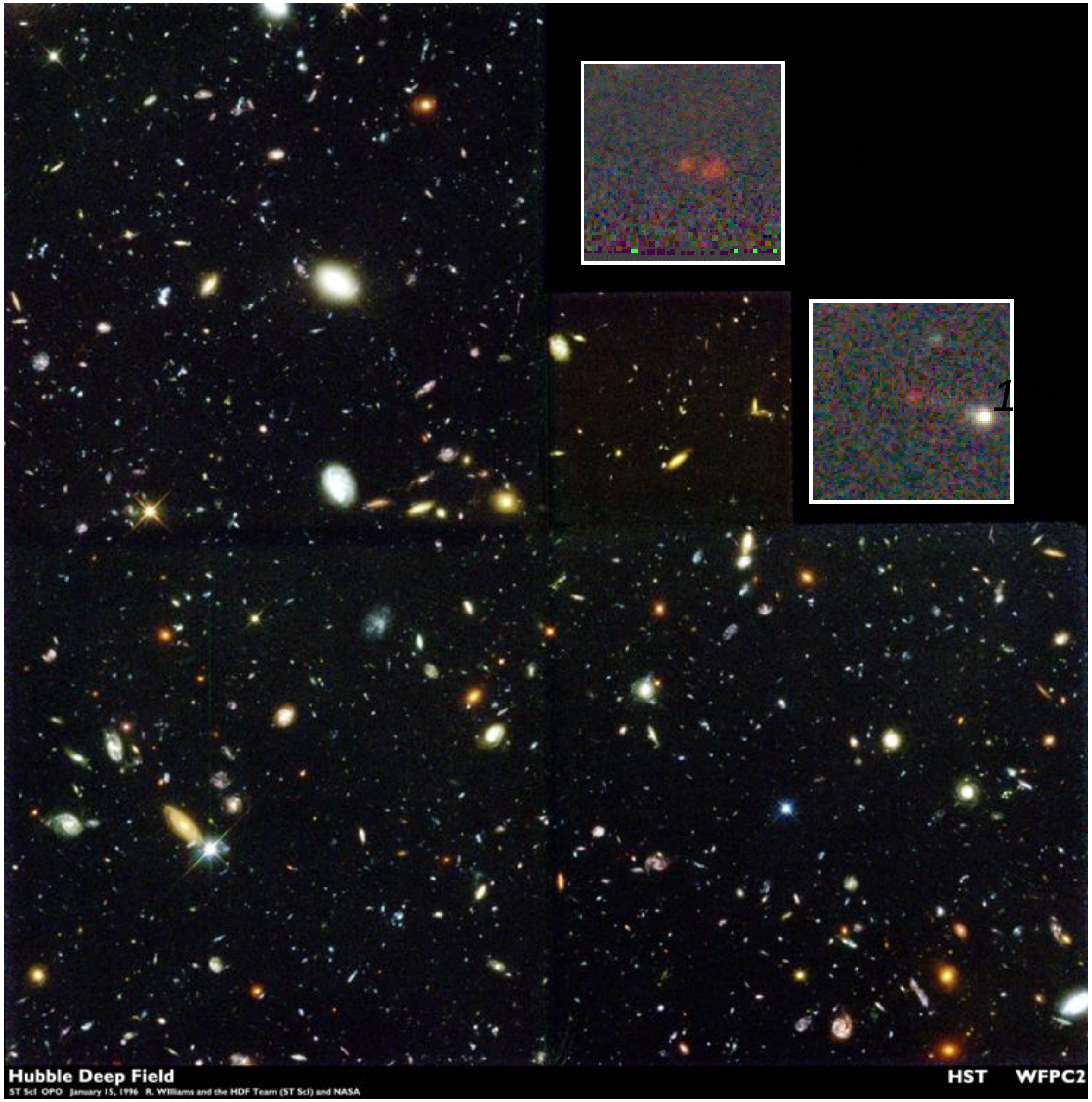
Light from the first galaxies is redshifted from the visible into the infrared.

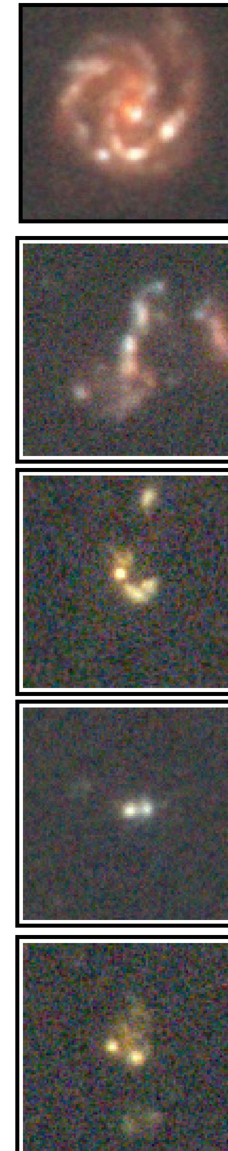






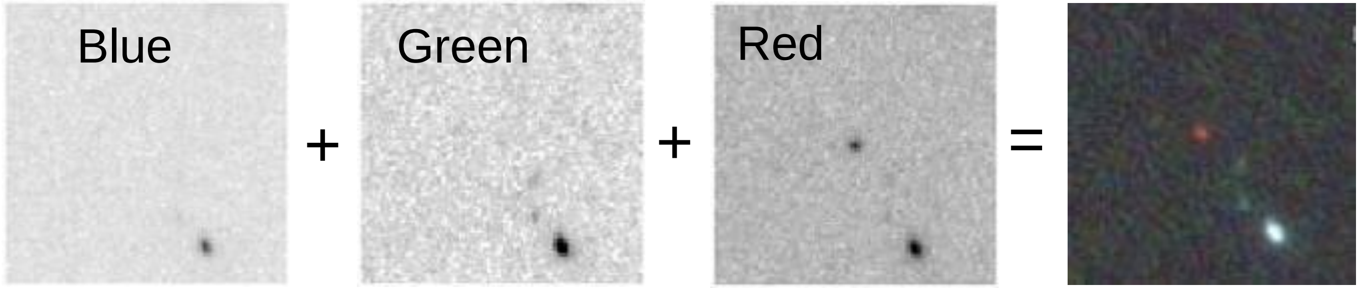
The Hubble Deep Field



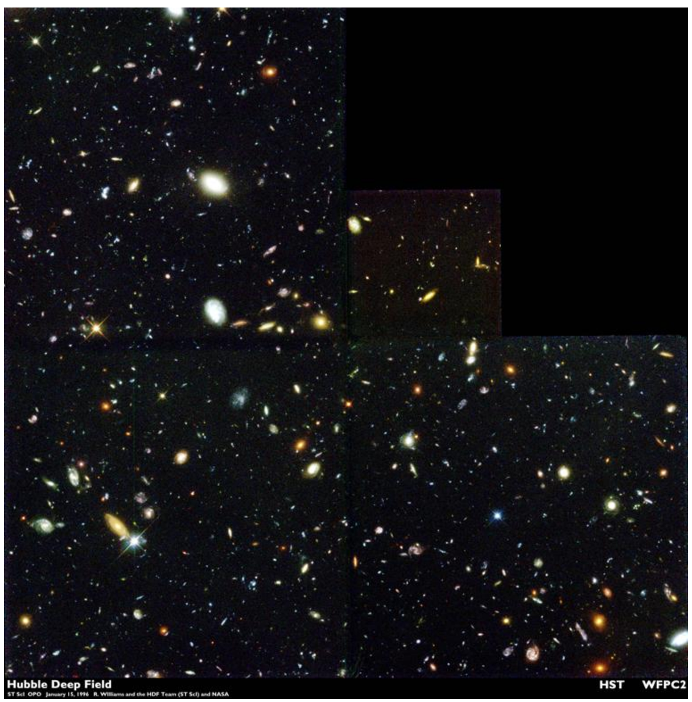


STScI Science Project: Robert Williams. et al. (1997)

How do we see first light objects?

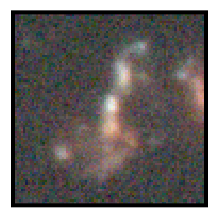


Deep Imaging: Look for *near-IR drop-outs*

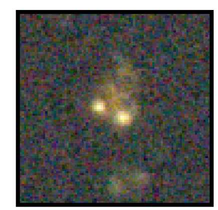


5.8 Gyr

2.2 Gyr

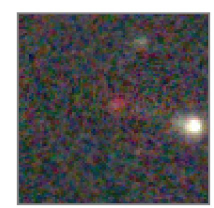


3.3 Gyr

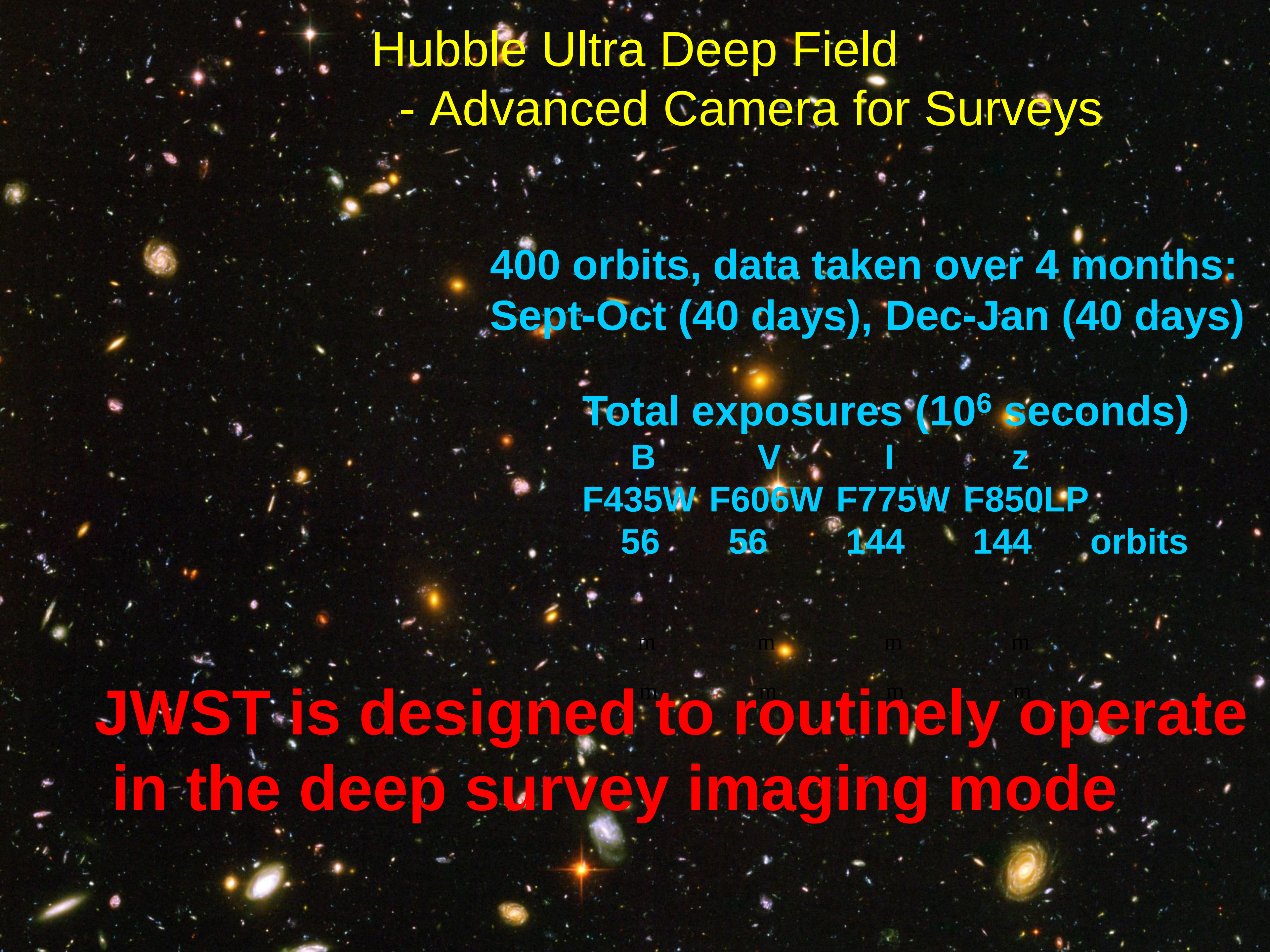


1.8 Gyr

2.2 Gyr



1.0 Gyr



Hubble Ultra Deep Field
- Advanced Camera for Surveys

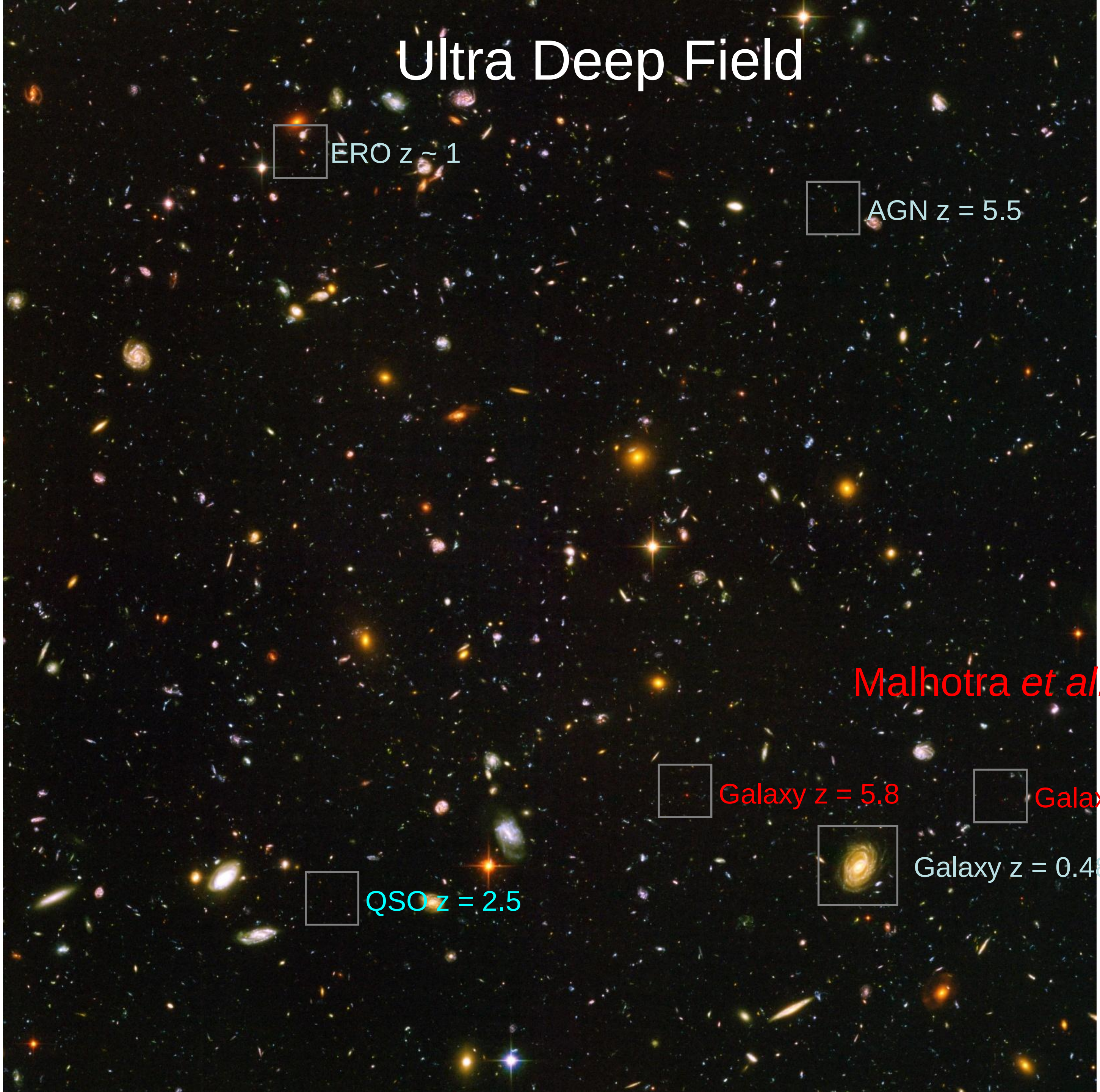
400 orbits, data taken over 4 months:
Sept-Oct (40 days), Dec-Jan (40 days)

Total exposures (10^6 seconds)

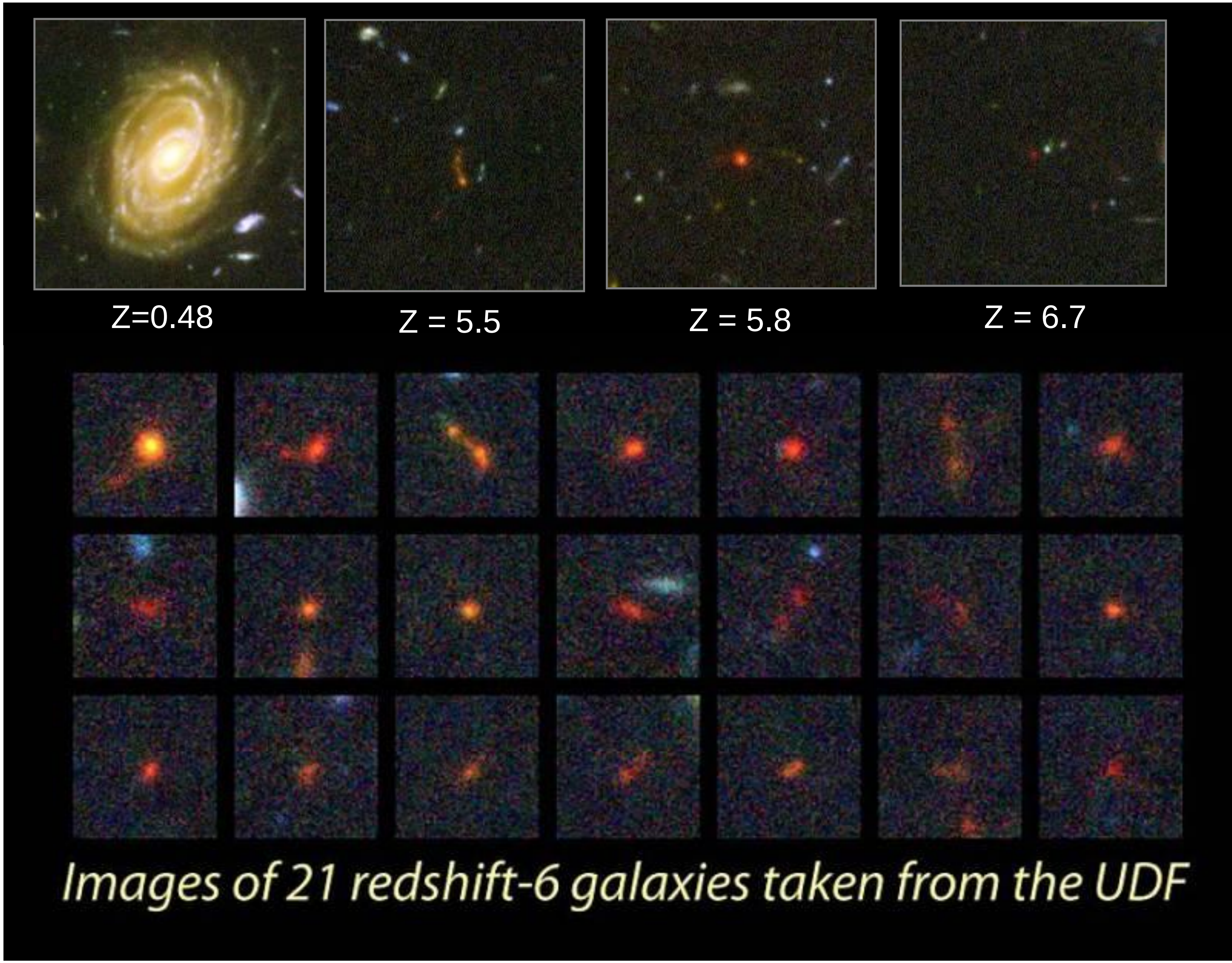
B	V	I	z	
F435W	F606W	F775W	F850LP	
56	56	144	144	orbits
m	m	m	m	
m	m	m	m	

JWST is designed to routinely operate in the deep survey imaging mode

Ultra Deep Field

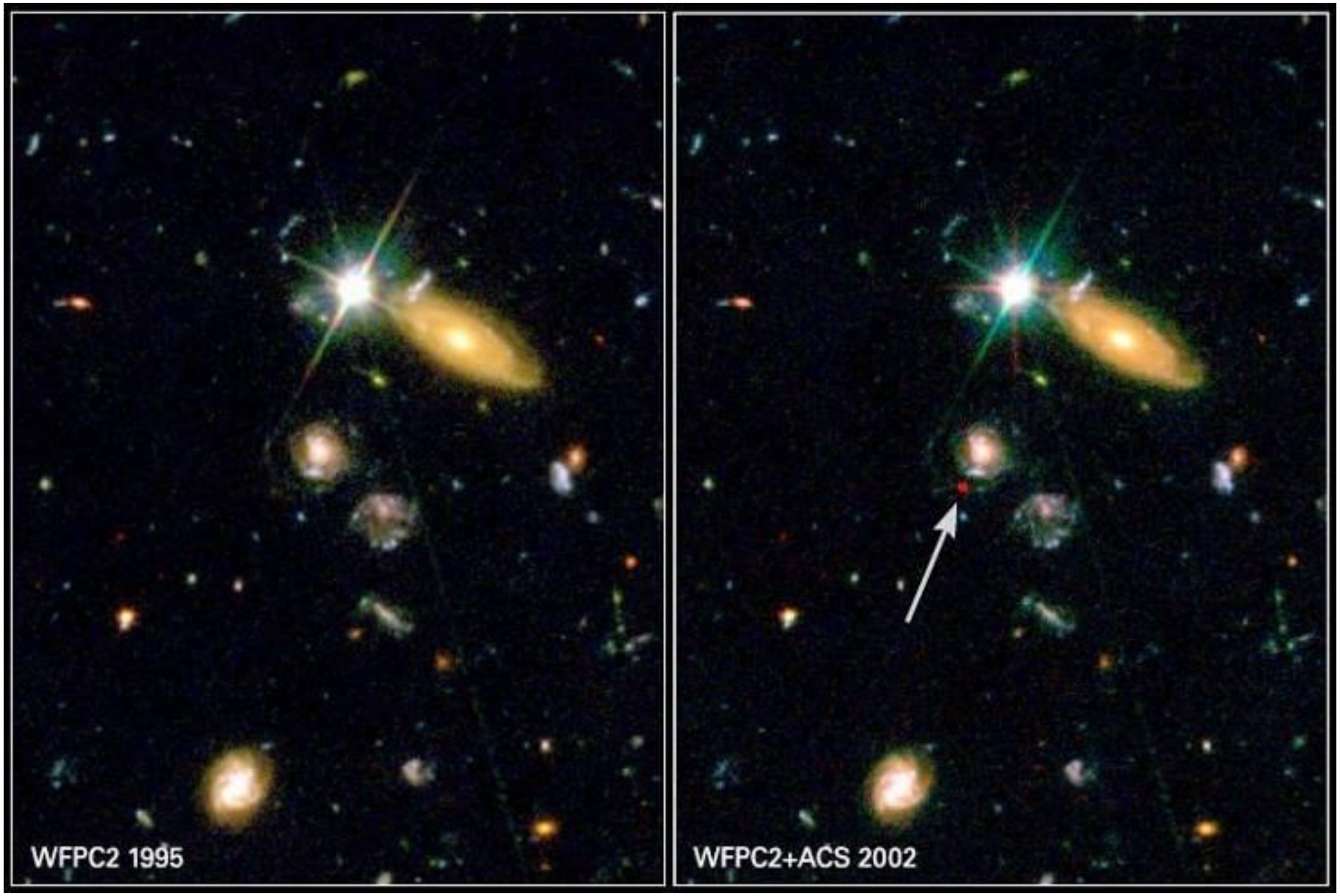


New Results from UDF



How do we see first light objects?

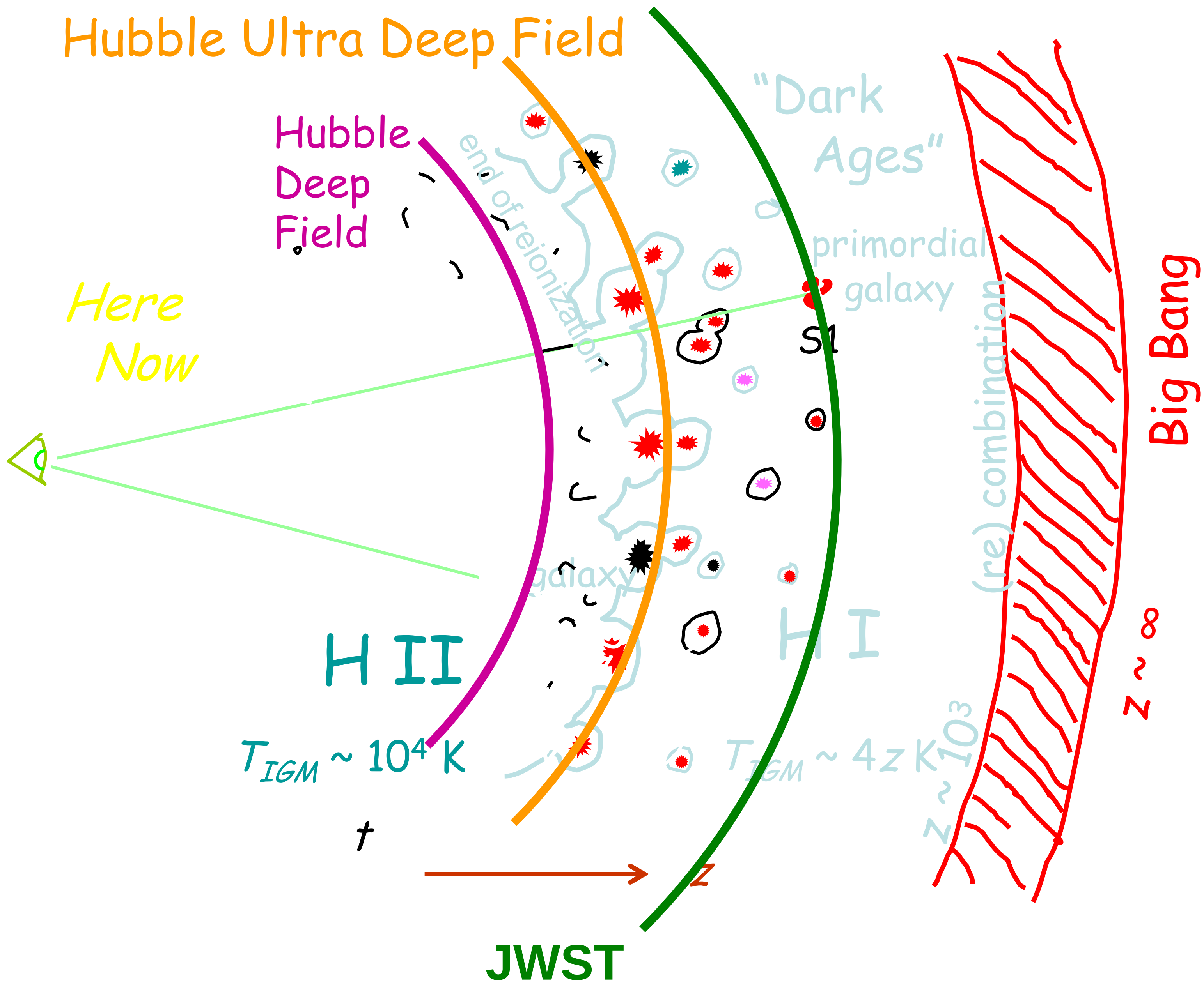
The first stars may be detected when they became bright supernovae. But, they will be very rare objects!



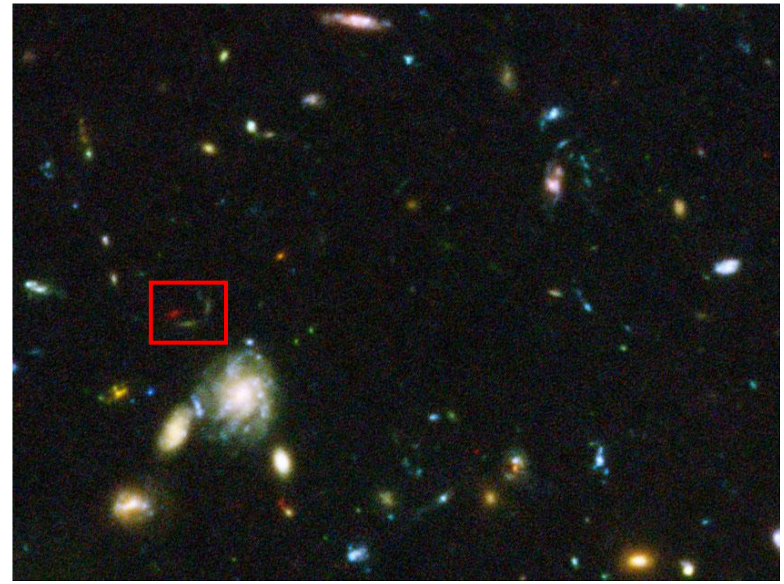
How do we see first light objects?

Use a magnifying glass !

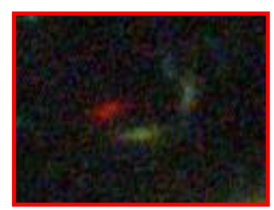
The Renaissance after the Dark Ages



Sensitivity Matters

GOODS CDFS – 13 orbits HUDF – 400 orbits

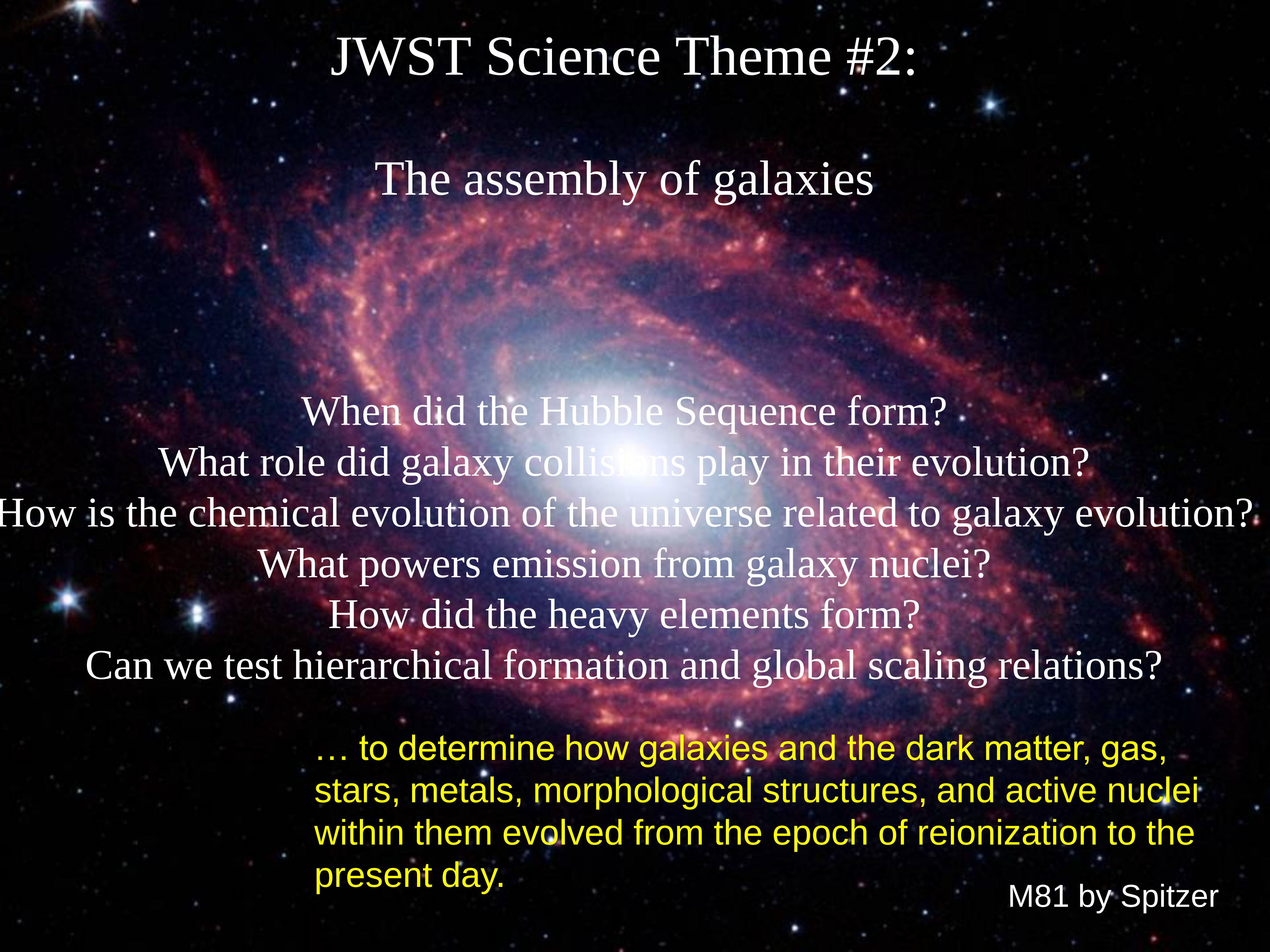
 

JWST Science Theme #2:

The assembly of galaxies

When did the Hubble Sequence form?
What role did galaxy collisions play in their evolution?
How is the chemical evolution of the universe related to galaxy evolution?
What powers emission from galaxy nuclei?
How did the heavy elements form?
Can we test hierarchical formation and global scaling relations?

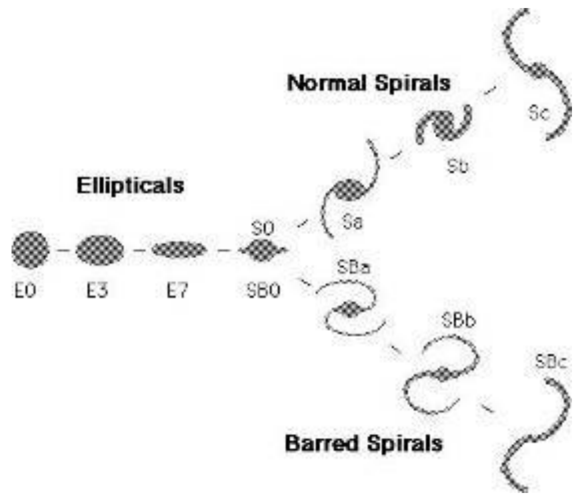
… to determine how galaxies and the dark matter, gas, stars, metals, morphological structures, and active nuclei within them evolved from the epoch of reionization to the present day.



M81 by Spitzer

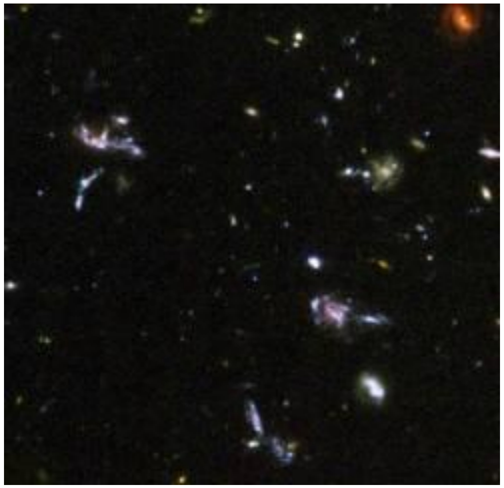
The Hubble Sequence

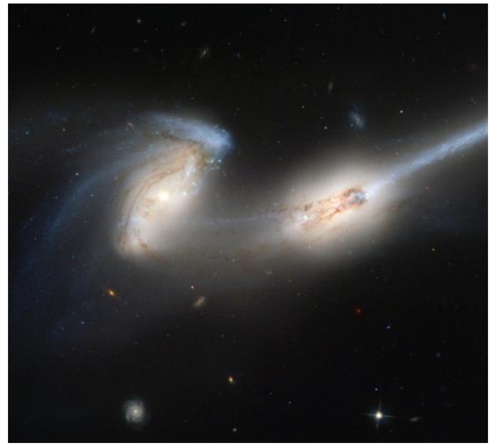
Hubble classified nearby (present-day) galaxies into Spirals and Ellipticals.

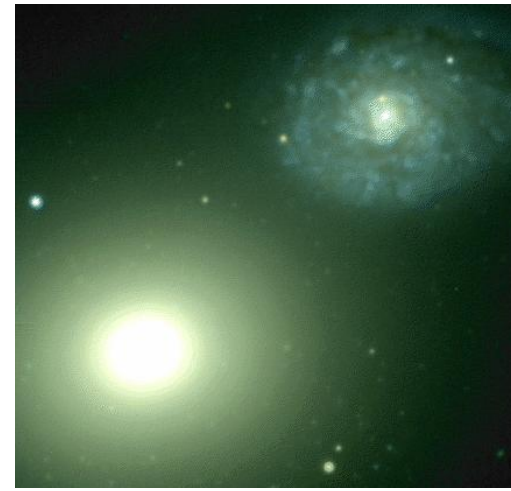


The Hubble Space Telescope has extended this to the distant past.

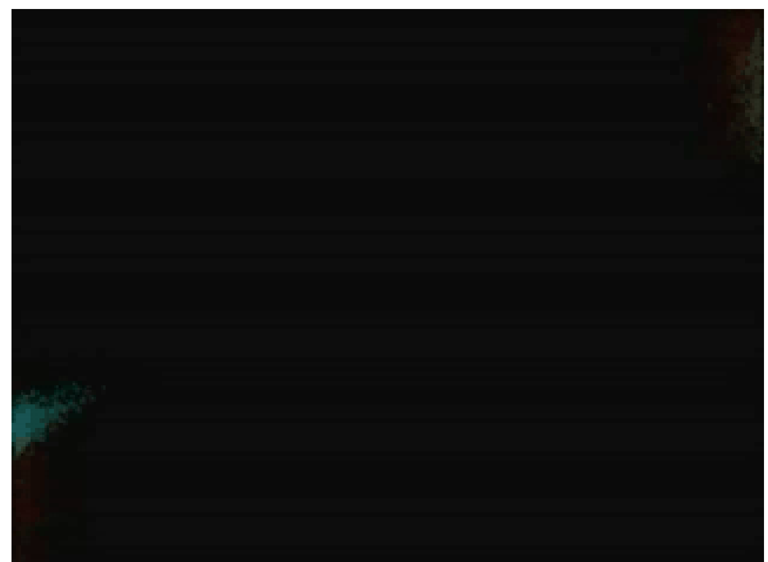
Where and when did the Hubble Sequence form?
How did the heavy elements form?



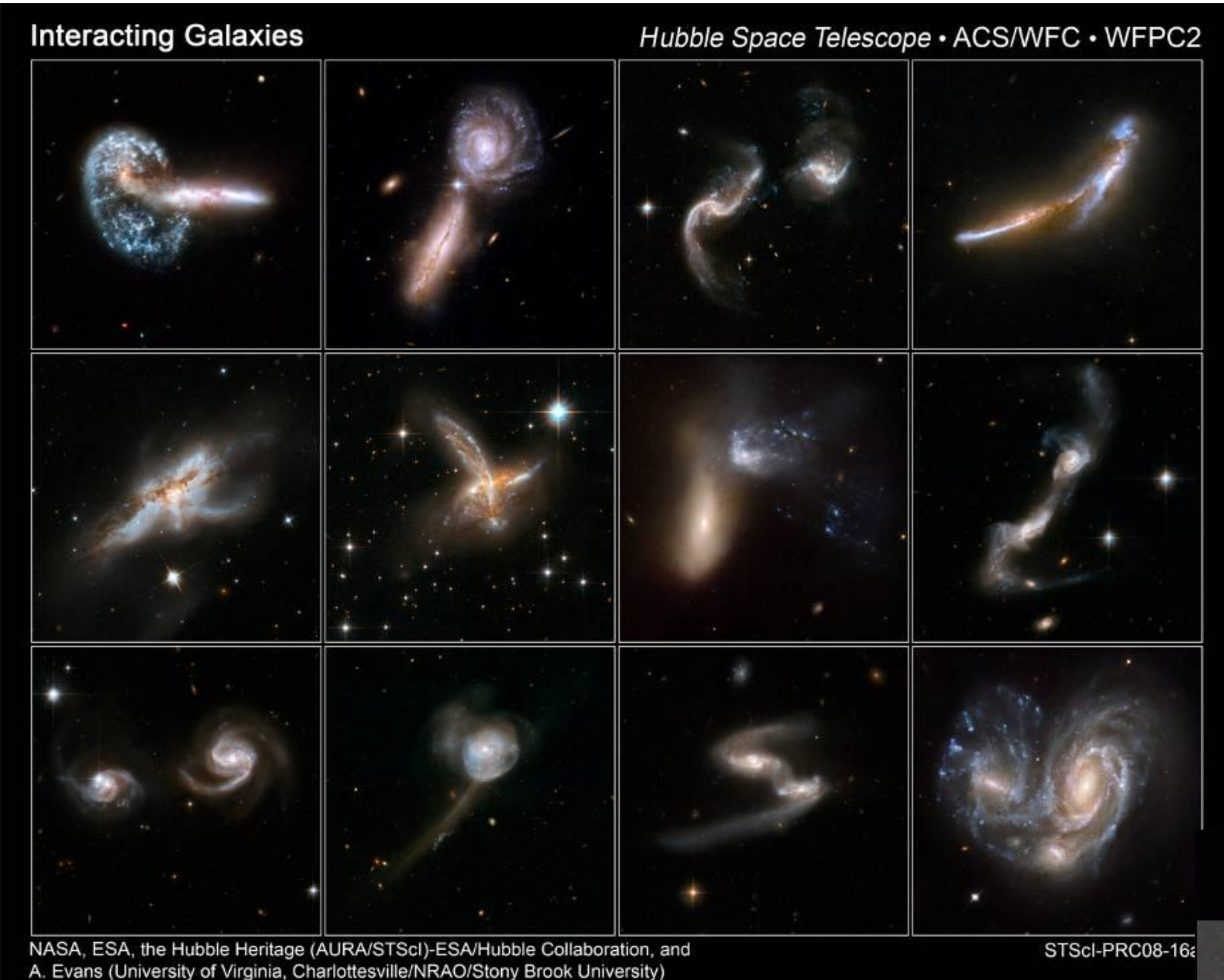


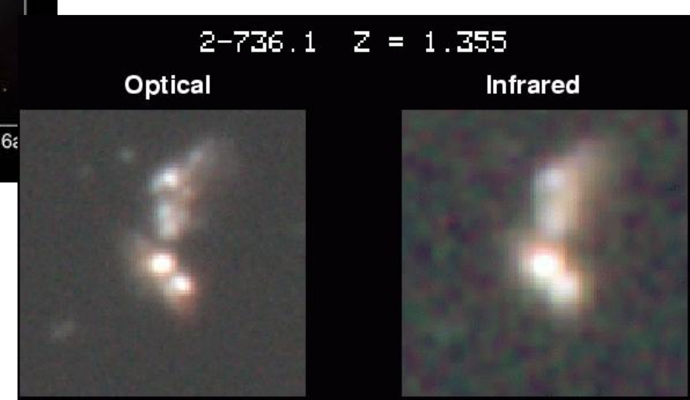


- Galaxy assembly is a process of hierarchical merging
- Components of galaxies have variety of ages & compositions
- JWST Observations:
  - Wide-area near-infrared imaging survey
  - Low and medium resolution spectra of 1000s of galaxies at high redshift
  - Targeted observations of galactic nuclei

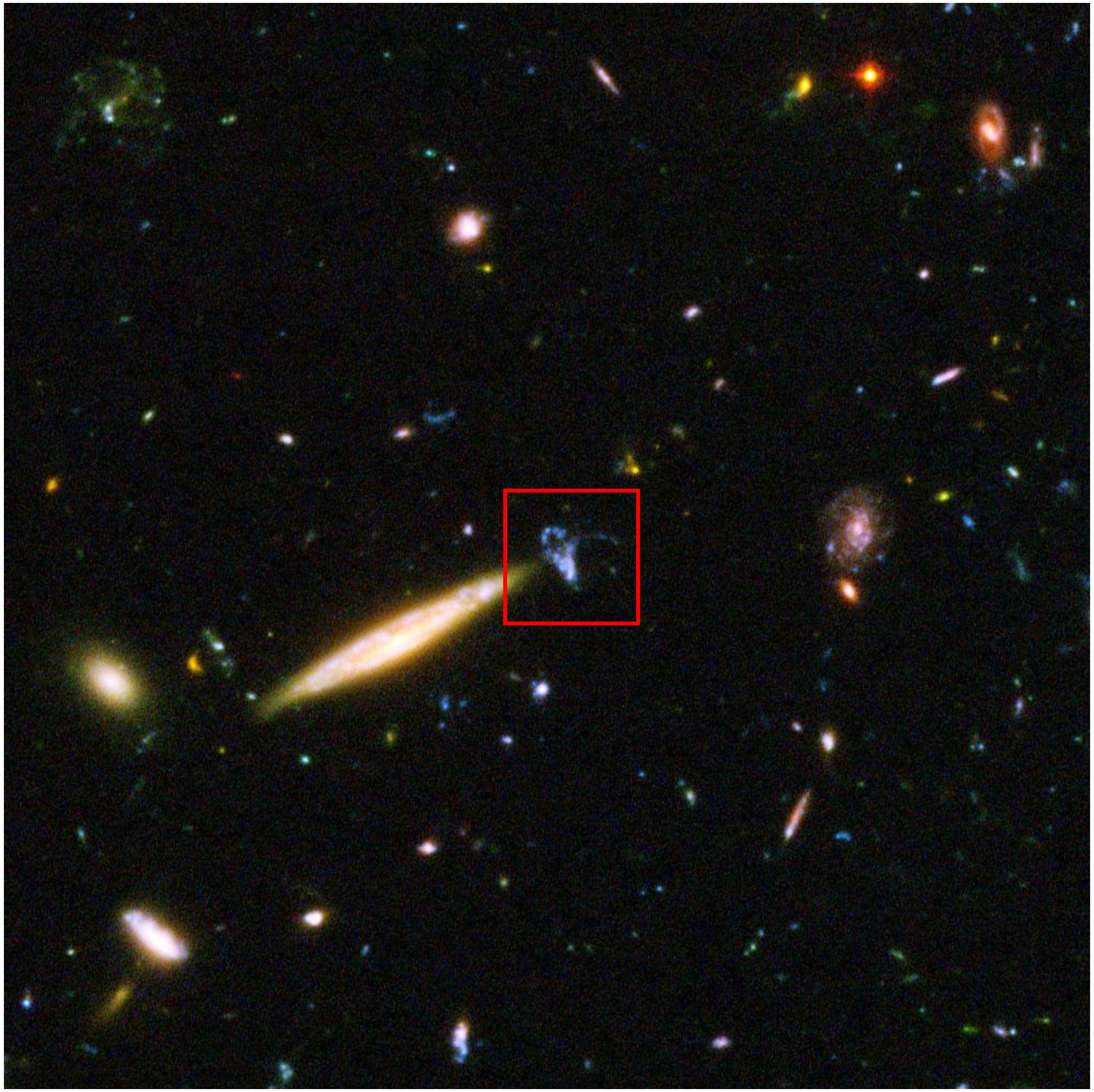


Distant Galaxies are “Train Wrecks”



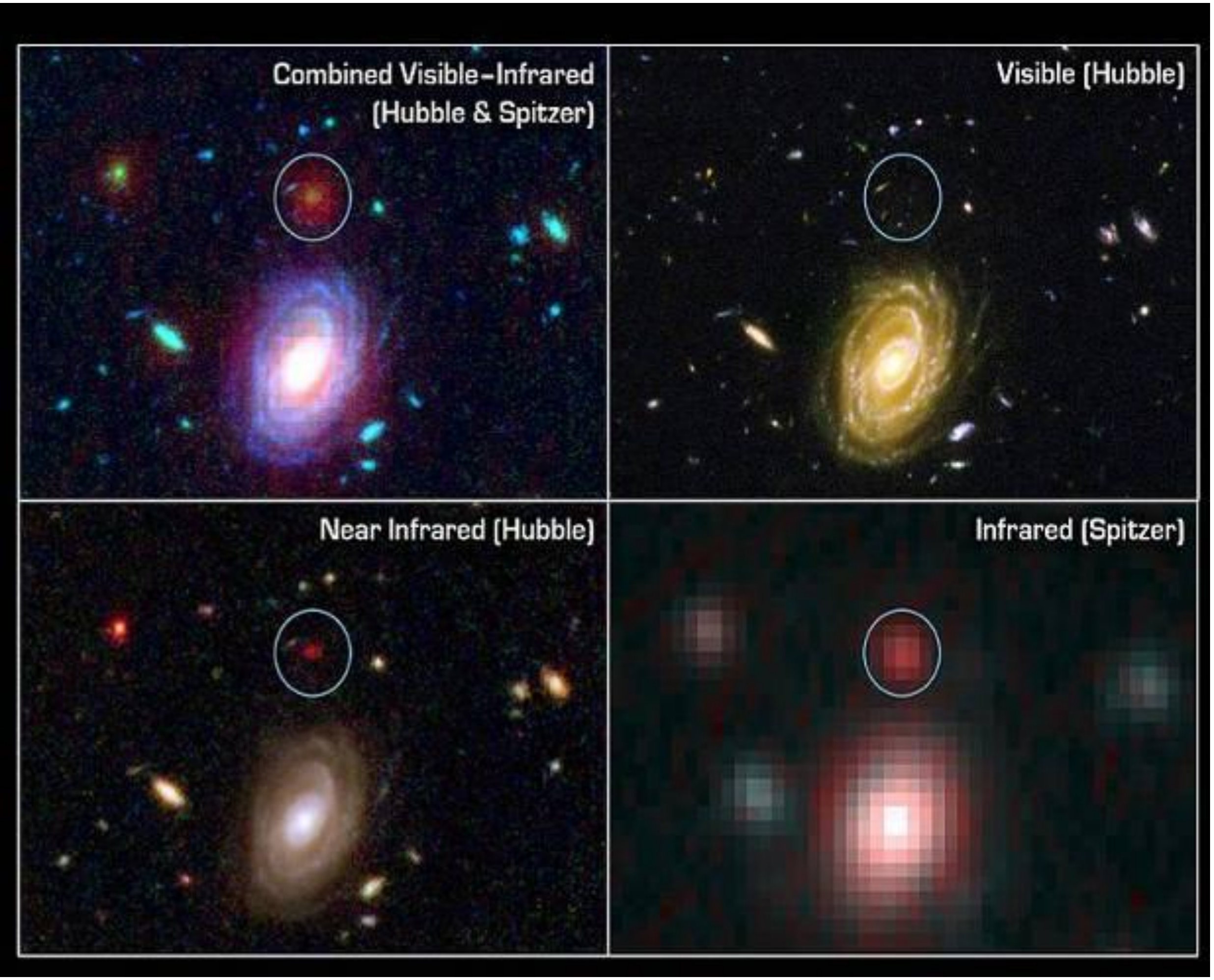


Unusual objects



Clusters of Galaxies

Unexpected "Big Babies"



Spitzer and Hubble have identified a dozen very old (almost 13 Billion light years away) very massive (up to 10X larger than our Milky Way) galaxies.

At an epoch when the Universe was only ~15% of its present size, and ~7% of its current age.

This is a surprising result unexpected in current galaxy formation models.

Michael Werner, "Spitzer Space Telescope", William H. Pickering Lecture, AIAA Space 2007.

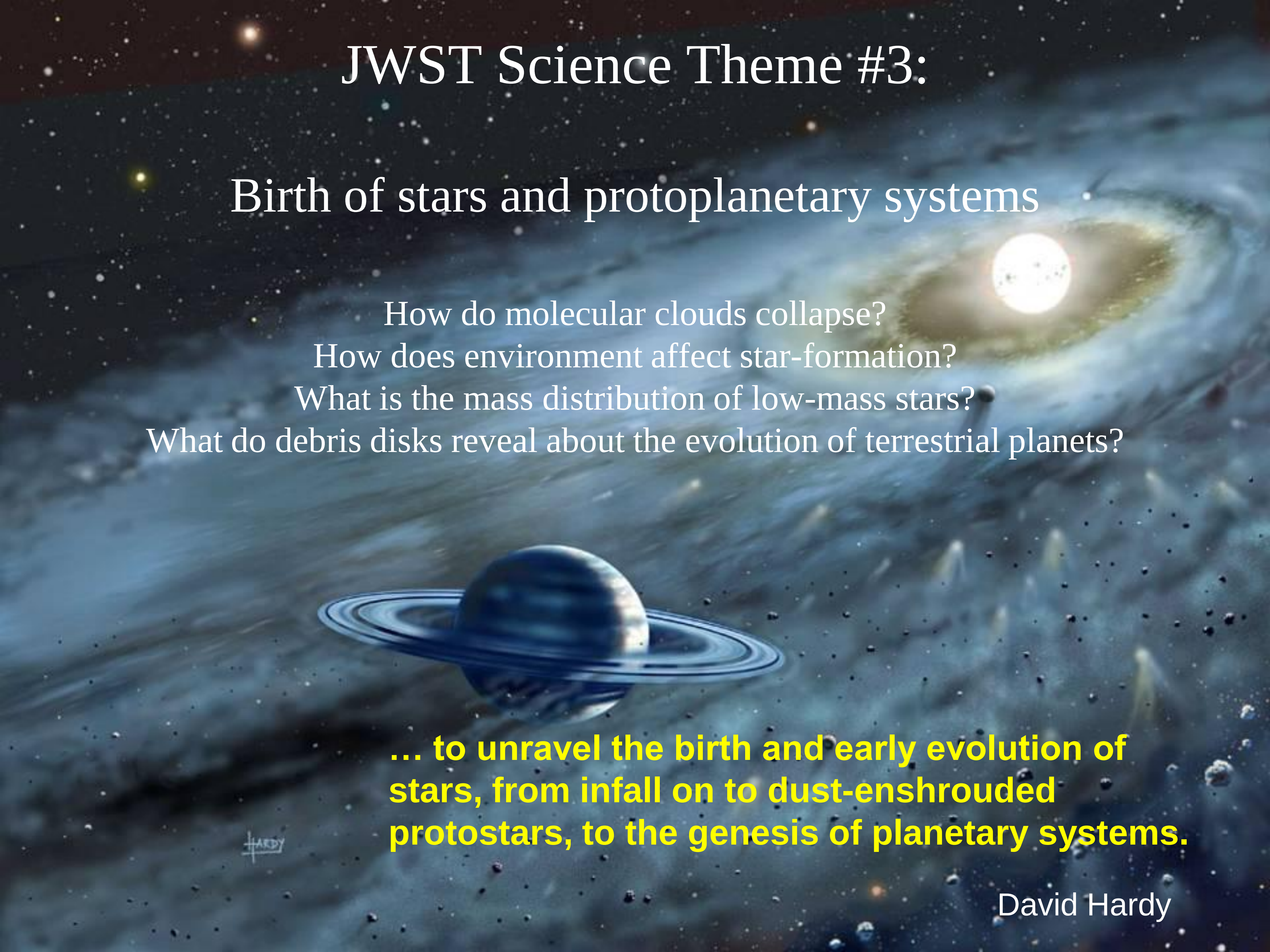
….Hence Science News reports that Spitzer and Hubble posed a Cosmic Conundrum by finding these very massive galaxies in the early Universe….This challenges theories of structure formation

Mich… …ner, “Spitzer Space Telescope”, William H. Pickering Lecture, AIAA Space 2007.

JWST Science Theme #3:

Birth of stars and protoplanetary systems

How do molecular clouds collapse?
How does environment affect star-formation?
What is the mass distribution of low-mass stars?
What do debris disks reveal about the evolution of terrestrial planets?



… to unravel the birth and early evolution of stars, from infall on to dust-enshrouded protostars, to the genesis of planetary systems.

David Hardy

How do proto-stellar clouds collapse?

Stars form in small regions collapsing gravitationally within larger molecular clouds.

Infrared sees through thick, dusty clouds

Proto-stars begin to shine within the clouds, revealing temperature and density structure.

Barnard 68 in infrared

Key JWST Enabling Requirements:

- High angular resolution near- & mid-IR imagery
- High angular resolution imaging spectroscopy

How does environment affect star-formation?

Massive stars produce wind & radiation

Either disrupt star formation, or causes it.

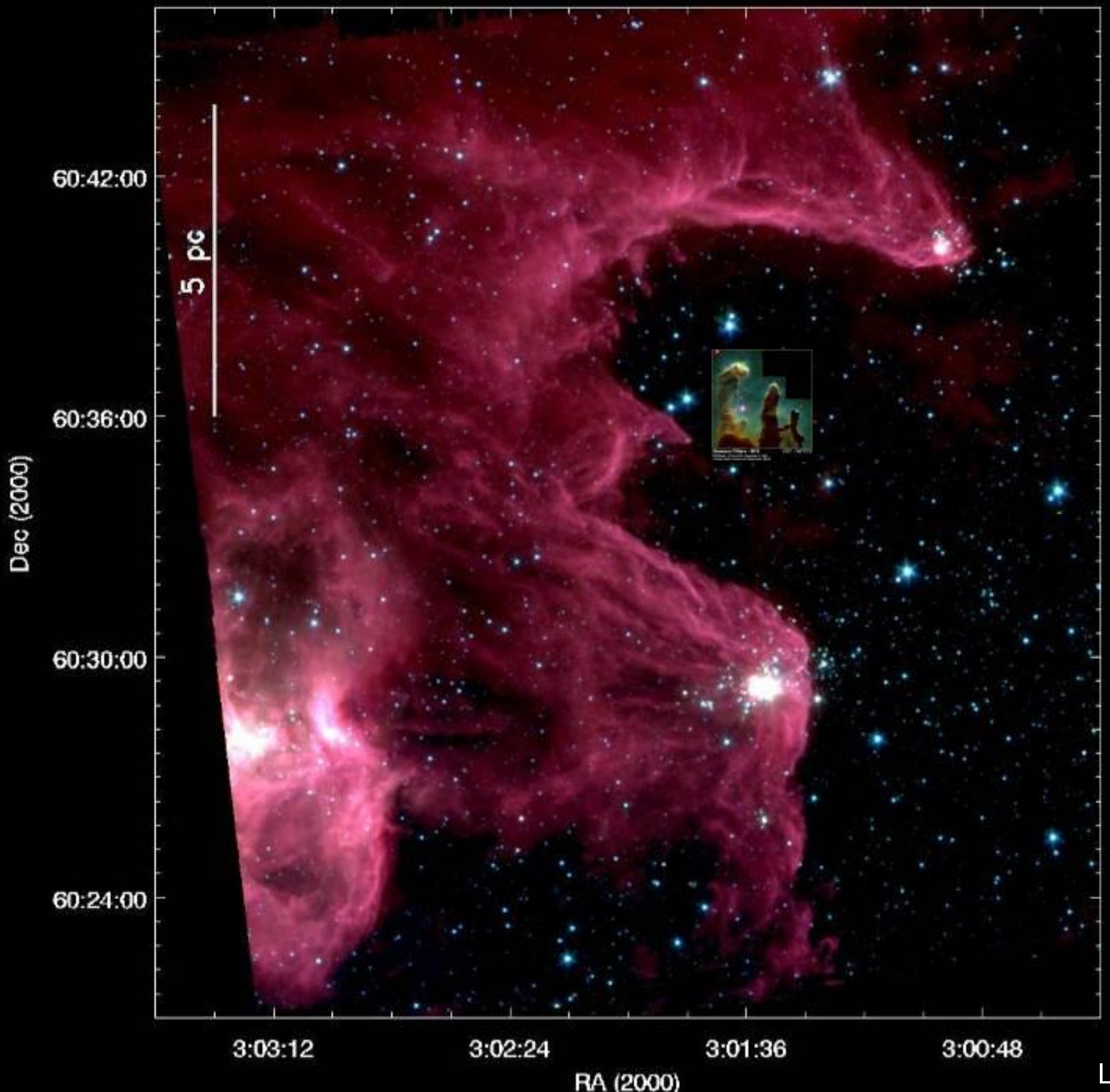
Boundary between smallest brown dwarf stars & planets is unknown

Different processes? Or continuum?

JWST Observations:

Survey dark clouds, “elephant trunks” or “pillars of creation” star-forming regions

The Eagle Nebula
as seen in the infrared

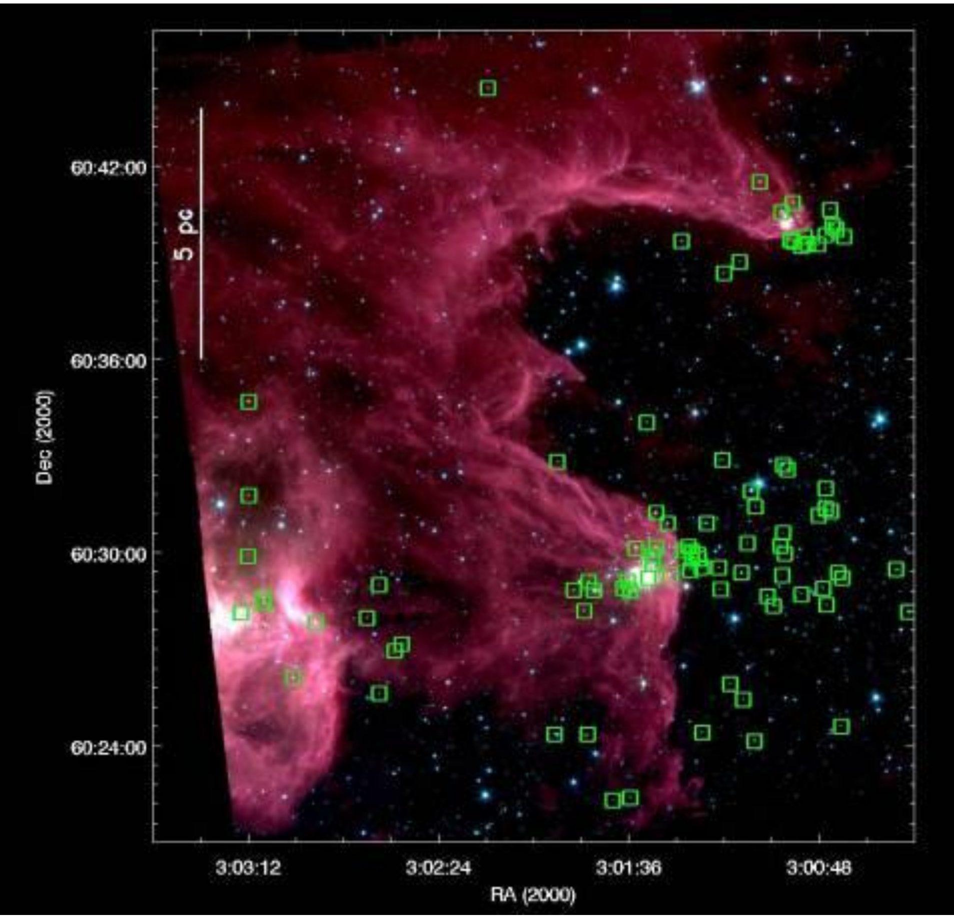


Spitzer has Found “The Mountains Of Creation”

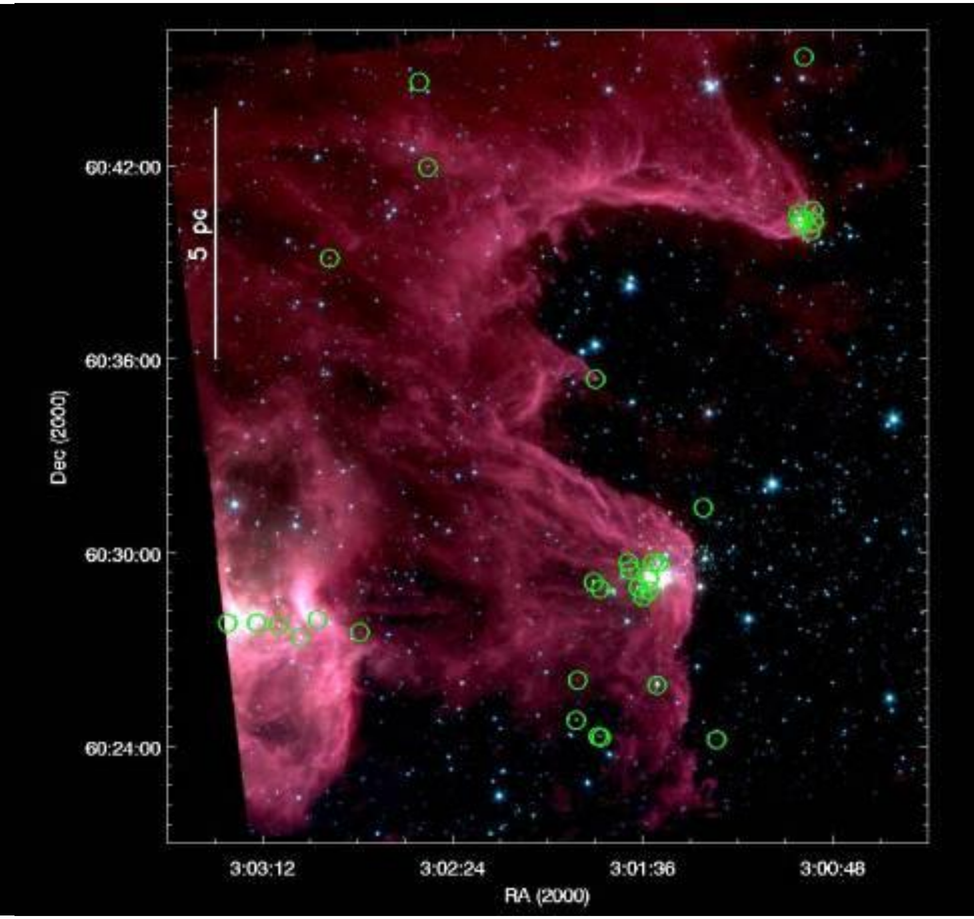
Michael Werner, “Spitzer Space Telescope”, William H. Pickering Lecture, AIAA Space 2007.

L. Allen, CfA [GTO]

The Mountains Tell Their Tale
Interstellar erosion & star formation propagate through the cloud



Young (Solar Mass) Stars are Shown in This Panel



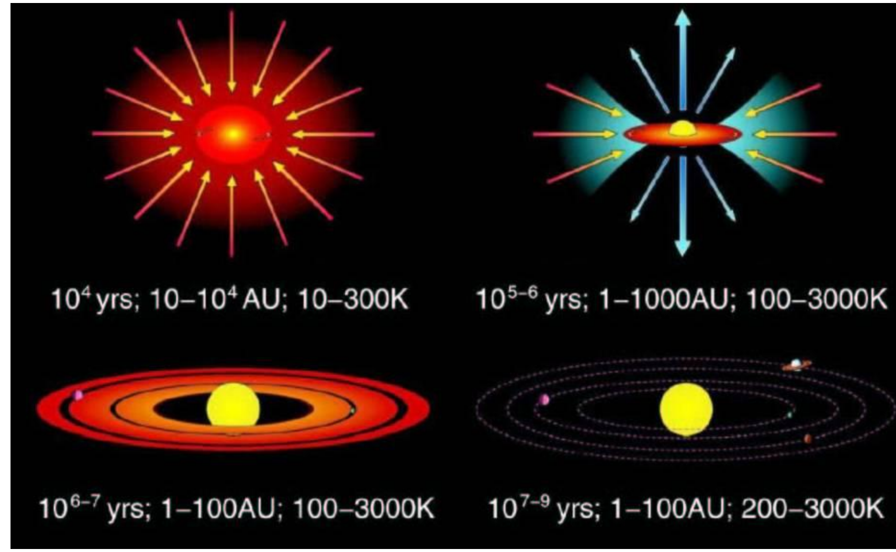
Really Young Stars are Shown in This Panel

Michael Werner, “Spitzer Space Telescope”, William H. Pickering Lecture, AIAA Space 2007.

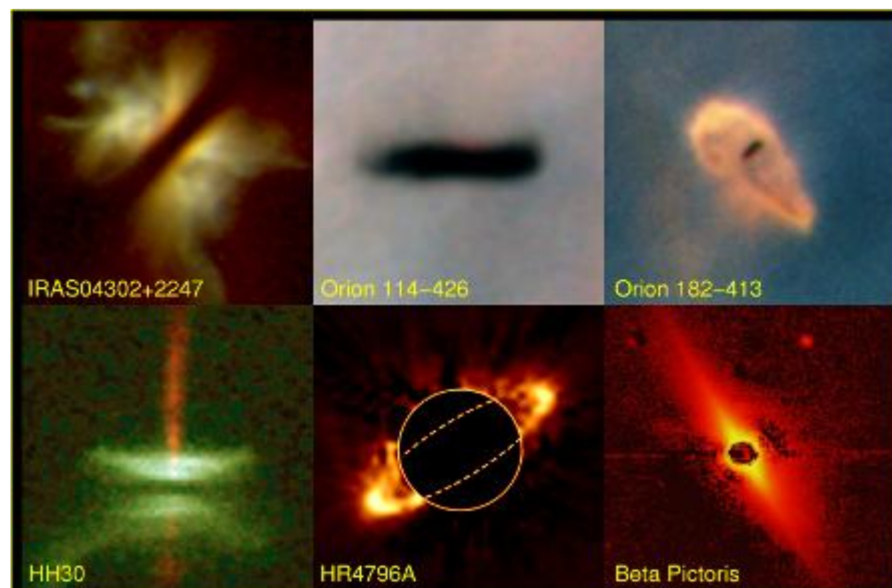
Birth of Stars and Proto-planetary Systems

- What is the role of molecular clouds, cores and their collapse in the evolution of stars and planetary systems?
- How do protostars form and evolve?
- How do massive stars form and interact with their environment?
- How do massive stars impact their environment by halting or triggering further star formation. How do they impact the evolution of disks?
- What is the initial mass function down to planetary masses?
- How do protoplanetary systems form and evolve?
- How do astrochemical tracers track star formation and the evolution of protoplanetary systems?

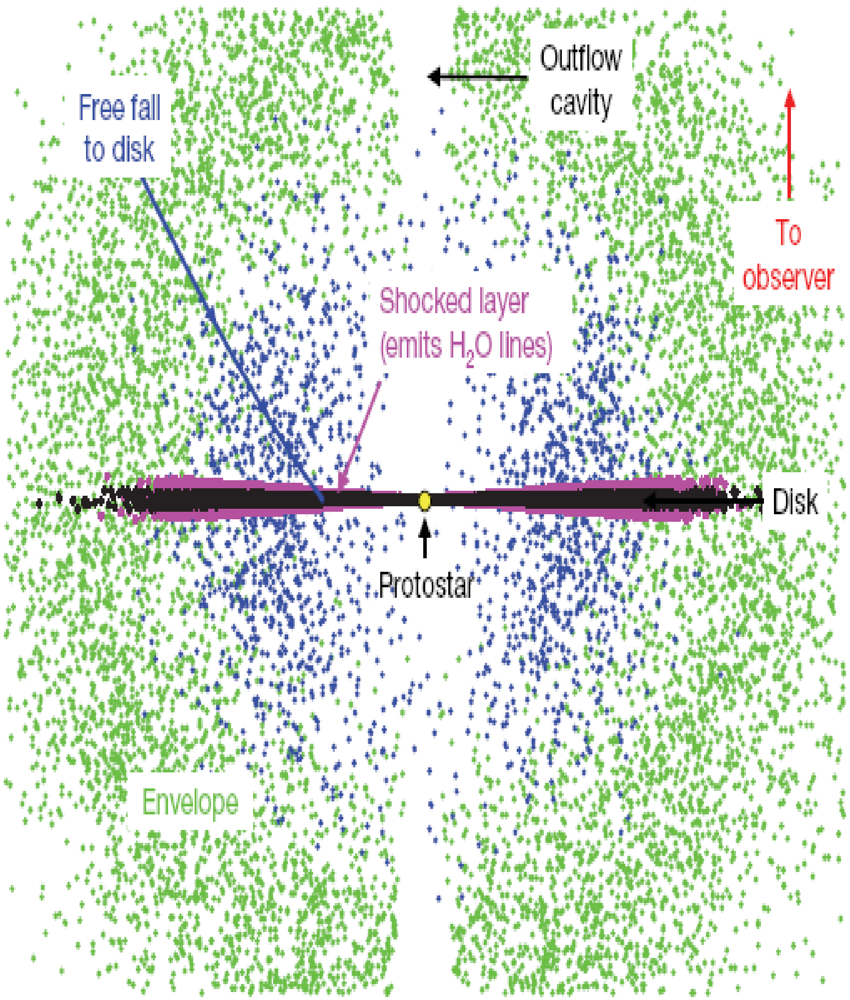
Deeply embedded protostar | Circumstellar disk

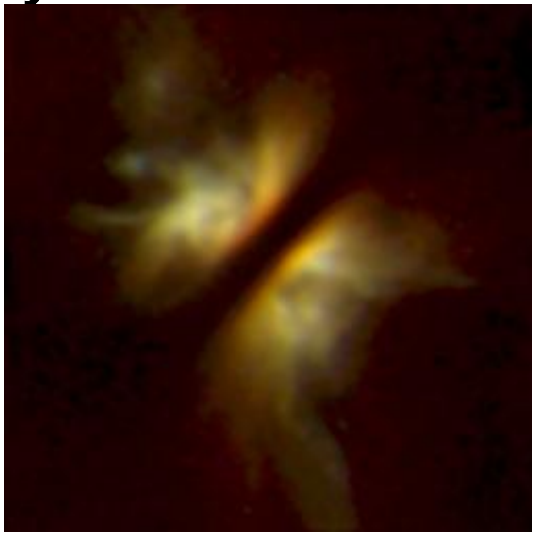


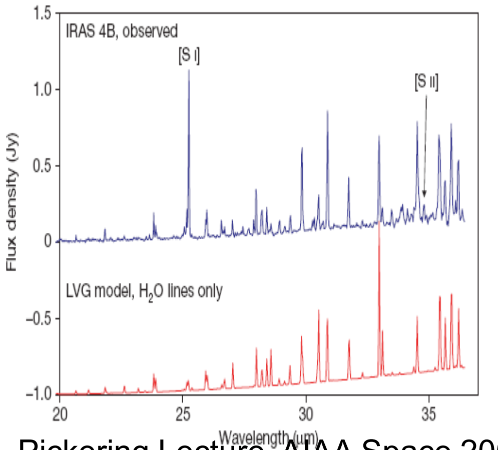
Agglomeration & planetesimals | Mature planetary system



How are Planets Assembled?
Spitzer Spectrum Shows Water Vapor Falling onto Protoplanetary Disk







Michael Werner, “Spitzer Space Telescope”, William H. Pickering Lecture, AIAA Space 2007.

Dust disks are durable and omnipresent

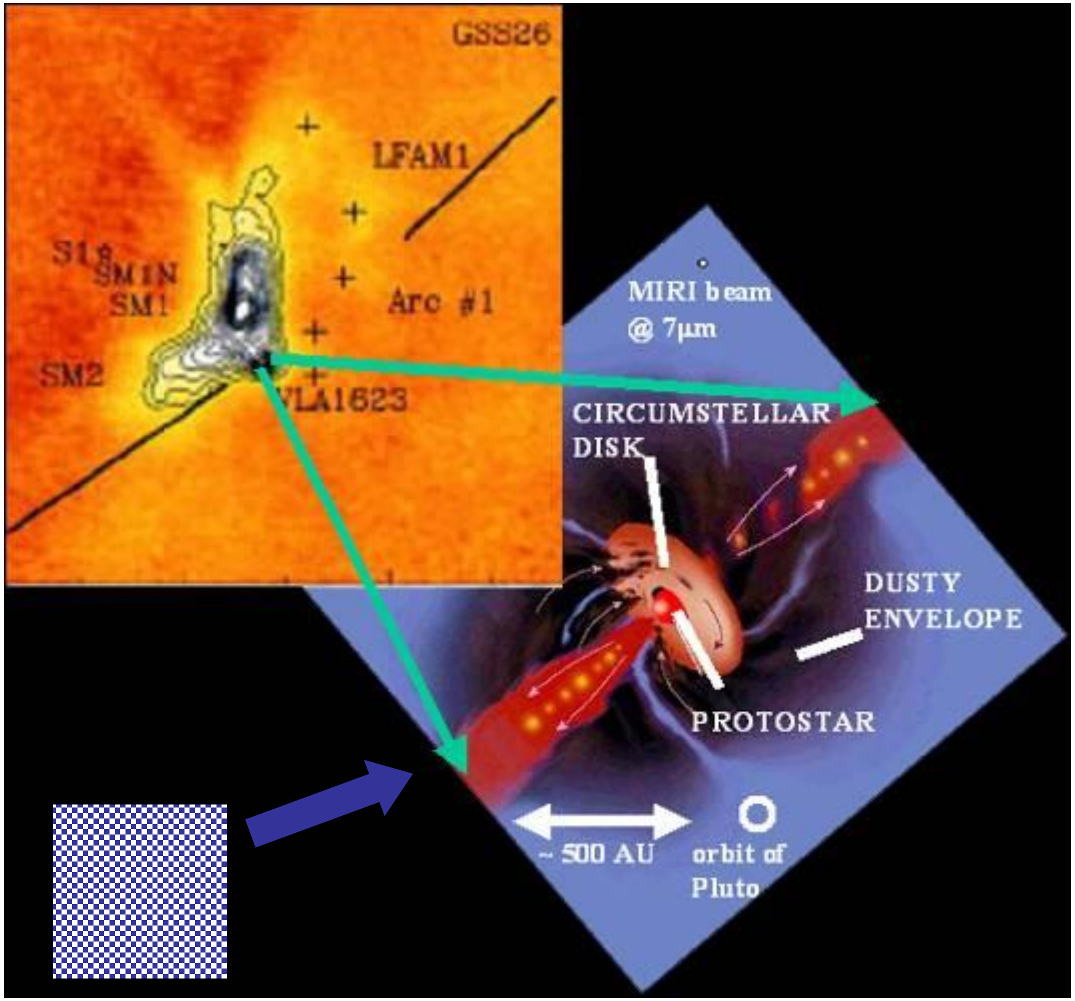
The central star of the Helix Nebula, a hot, luminous White Dwarf, shows an infrared excess attributable to a disk in a planetary system which survived the star's chaotic evolution

Michael Werner, "Spitzer Space Telescope", William H. Pickering Lecture, AIAA Space 2007.

How are circumstellar disks like our Solar System?

Here is an illustration of what MIRI might find within the very young core in Ophiuchus, VLA 1623

artist's concept of protostellar disk from T. Greene, Am. Scientist



approximate field for JWST NIRSpec & MIRI integral field spectroscopy

JWST Science Theme #4:

Planetary systems and the origins of life

How do planets form?
How are circumstellar disks like our Solar System?
How are habitable zones established?

… to determine the physical and chemical properties of planetary systems including our own, and to investigate the potential for the origins of life in those systems.

Robert Hurt

How do planets form?

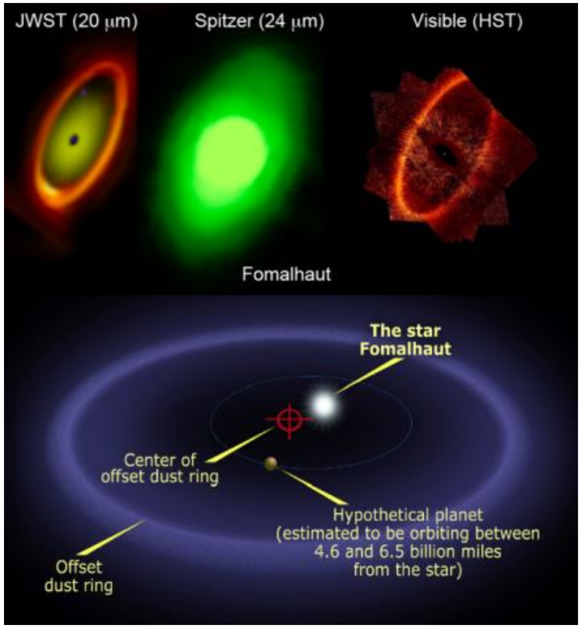
Giant planets could be signpost of process that create Earth-like planets

Solar System primordial disk is now in small planets, moons, asteroids and comets

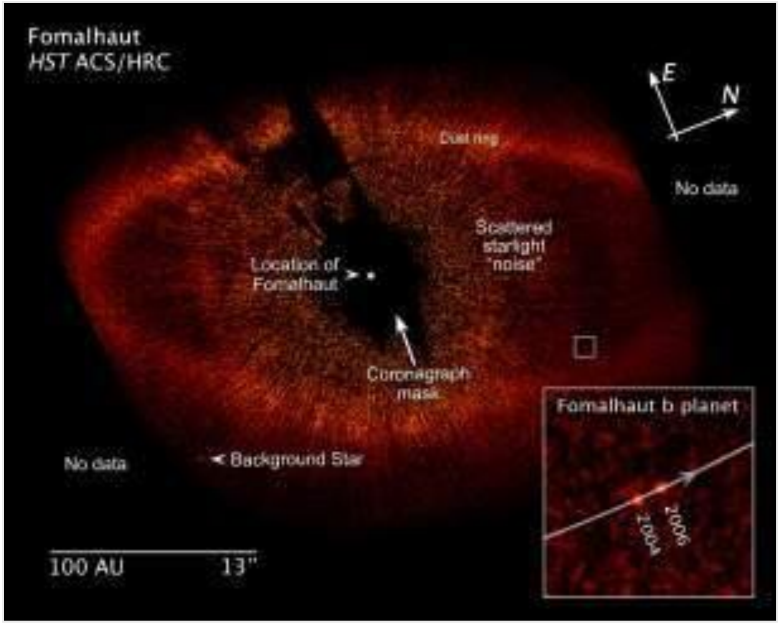
JWST Observations:

Coronagraphy of exosolar planets

Compare spectra of comets & circumstellar disks



Kalas, Graham & Clampin 2005



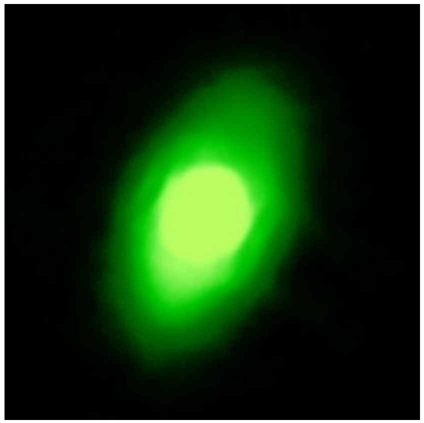
Kalas et al 2008

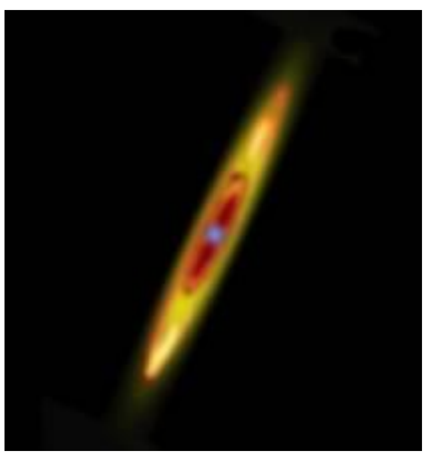
Planetary systems and the Origins of Life

Fomalhaut system at 24 µm

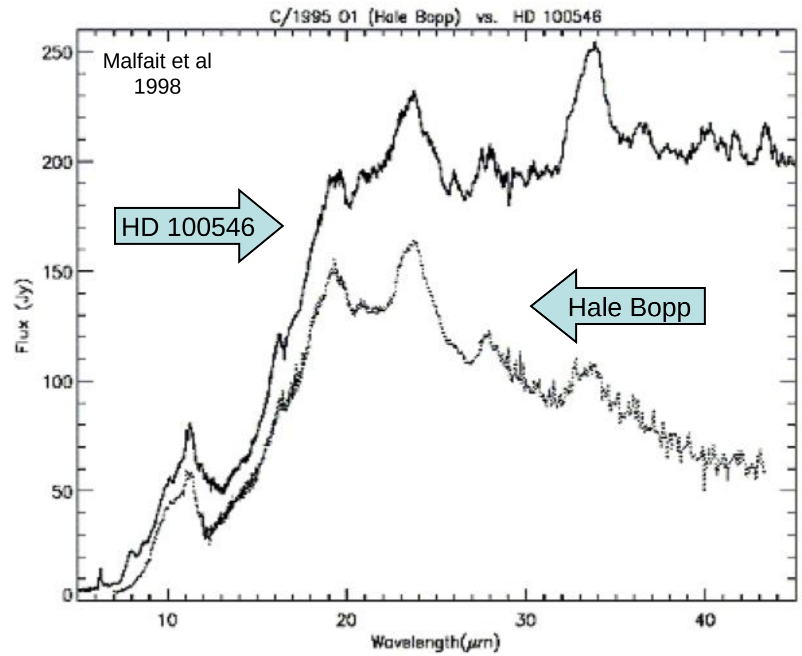
(Spitzer Space Telescope)

72”





Simulated JWST image
Fomalhaut at 24 microns



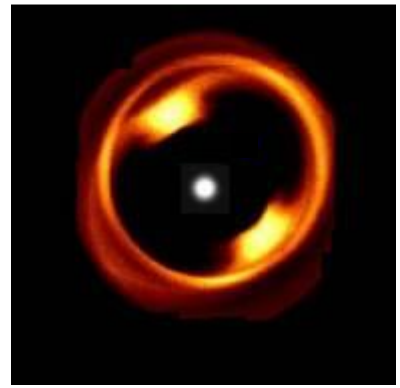
Malfait et al 1998

Planetary Systems and the Origins of Life

- How do planets and brown dwarfs form?
- How common are giant planets and what is their distribution of orbits?
- How do giant planets affect the formation of terrestial planets?
- What comparisons, direct or indirect, can be made between our Solar System and circumstellar disks (forming solar systems) and remnant disks?
- What is the source of water and organics for planets in habitable zones?
- How are systems cleared of small bodies?
- What are the planetary evolutionary pathways by which habitability is established or lost?
- Does our solar system harbor evidence for steps on these pathways?

Planetary Systems and the Origins of Life

Model of Vega system at 24 µm (Wilner et al. 2000)



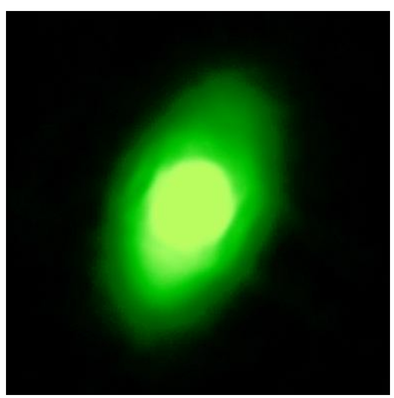
Formalhaut system at 24 µm

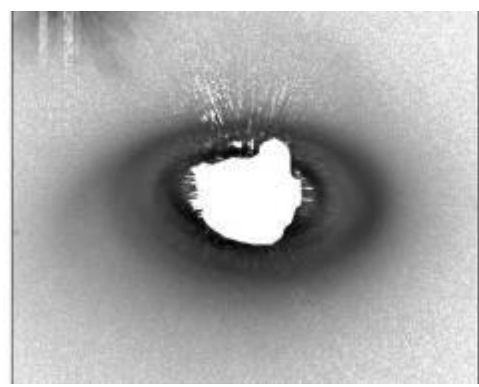
(Spitzer Space Telescope)

HD141569 (606 nm)

(HST/ACS)

72”





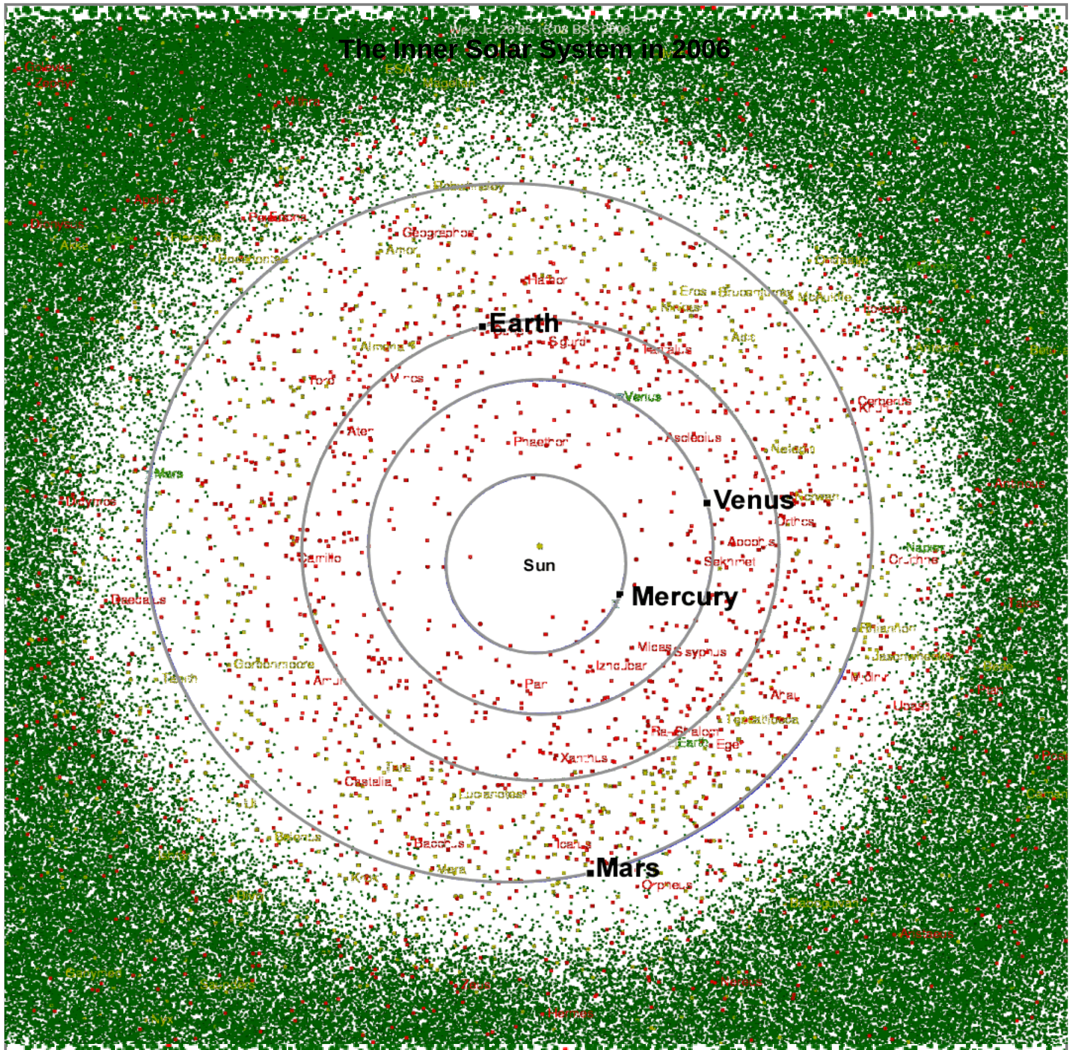
9”

History of Known (current) NEO Population

2006

Earth Crossing

Outside Earth's Orbit



Known

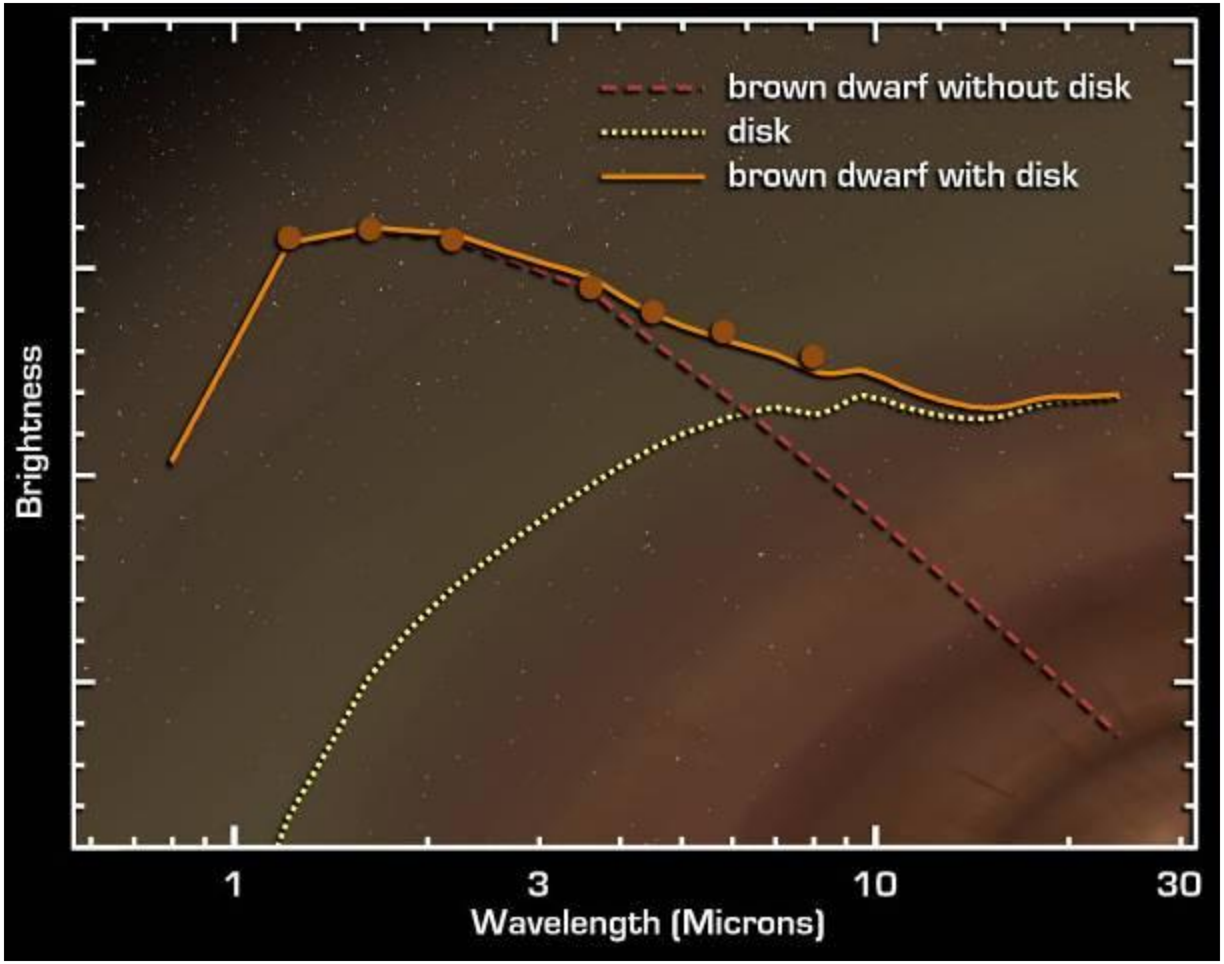
- **340,000 minor planets**
- **~4500 NEOs**
- **~850 Potentially Hazardous Objects (PHOs)**

Scott Manley

Armagh Observatory

Landis, "Piloted Flight to a Near-Earth Object", AIAA Conference 19 Sep 07

Brown Dwarfs Form Like Stars:
Can “Planets” have Planets?



A Brown Dwarf With a Planet-Forming Disk

Michael Werner, “Spitzer Space Telescope”, William H. Pickering Lecture, AIAA Space 2007.

How are habitable zones established?

Source of Earth's $H_2$0 and organics is not known

Comets? Asteroids?

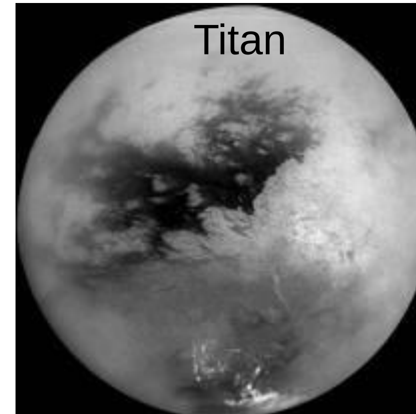
History of clearing the disk of gas and small bodies

Role of giant planets?

JWST Observations:

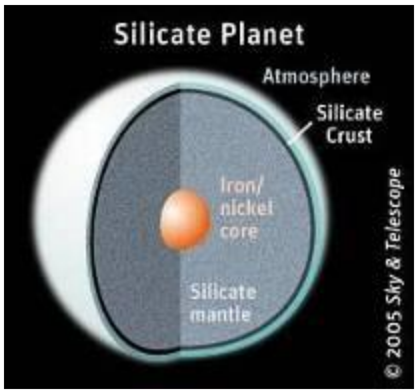
Comets, Kuiper Belt Objects

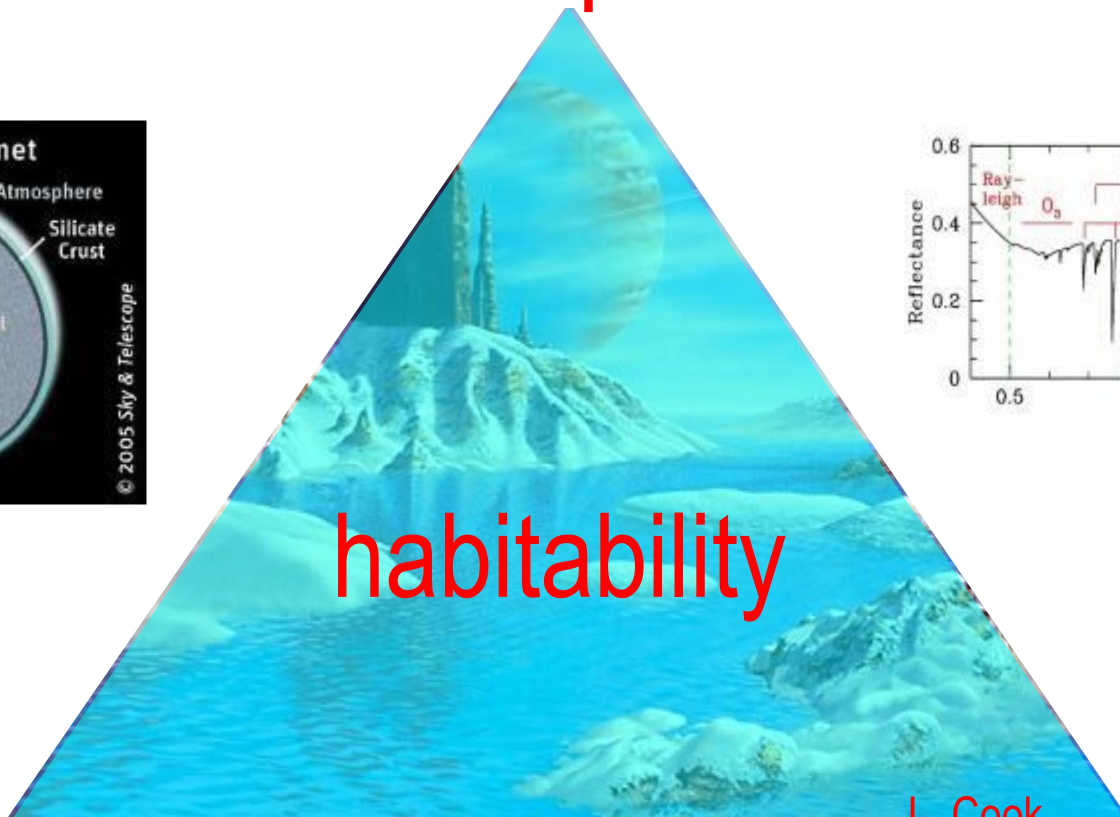
Icy moons in outer solar system

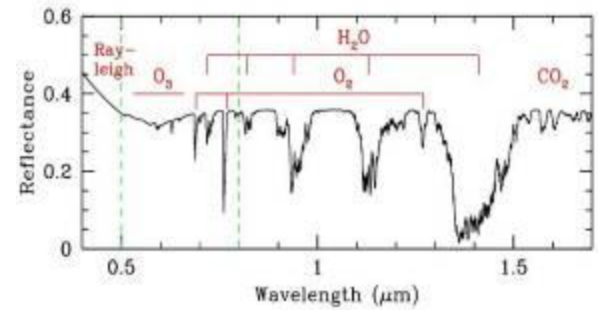


Search for Habitable Planets

atmosphere





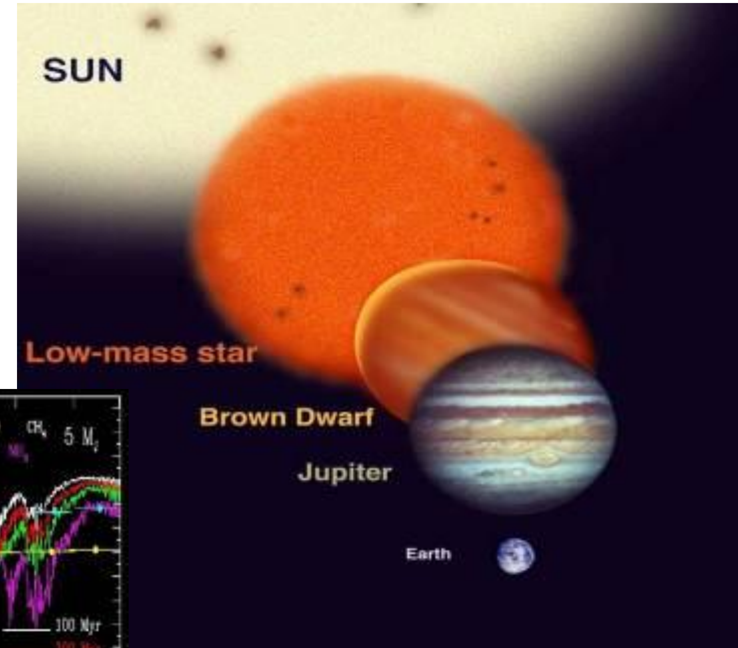


interior

surface

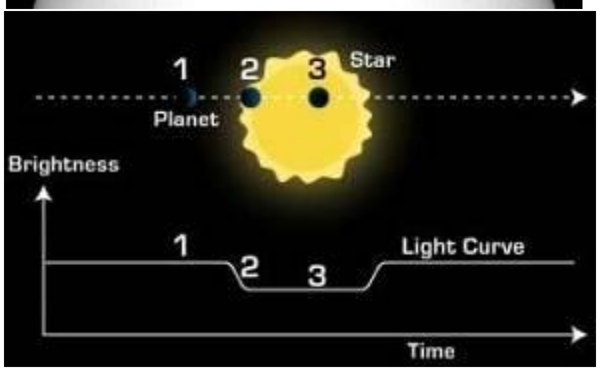
Sara Seager (2006)

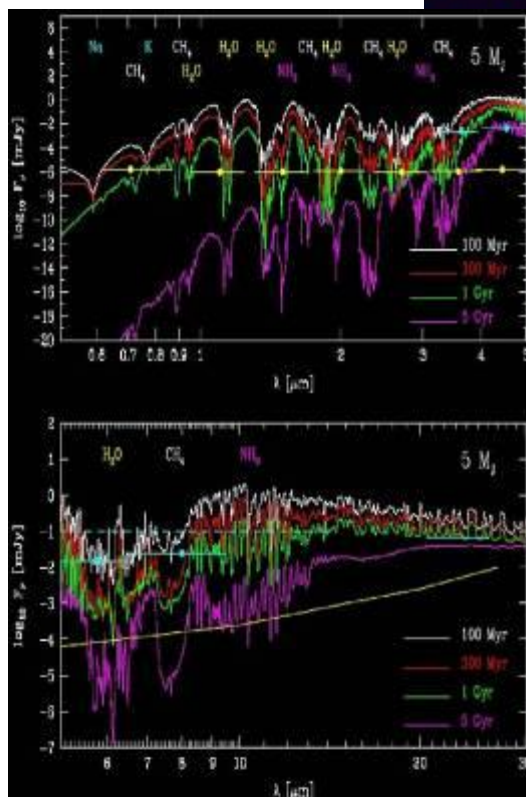
Atmospheres of Extrasolar Planets



Extrasolar Planet Transits

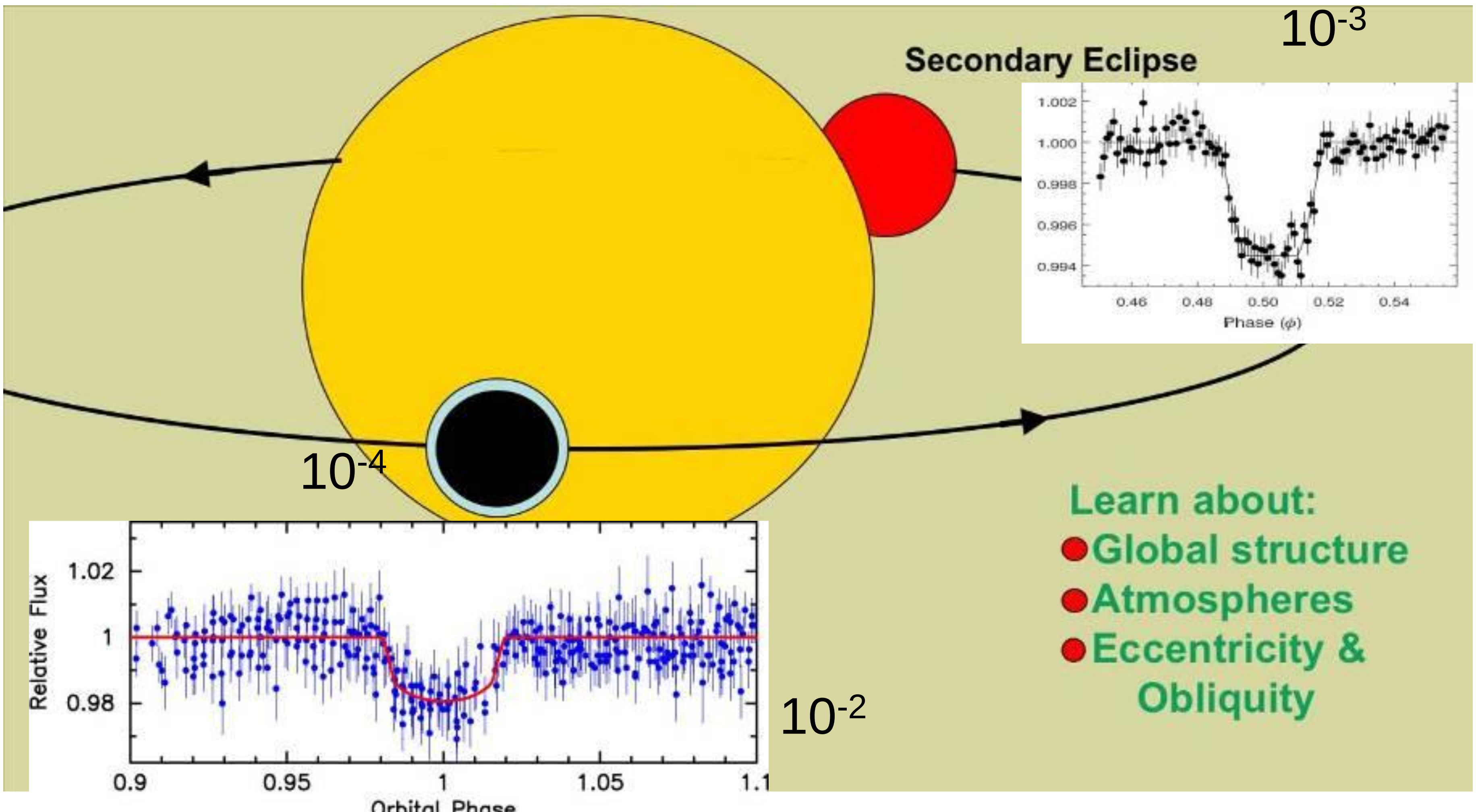
Detecting terrestrial planet atmospheres





Burrows, Sudarsky and Lunine (2003)

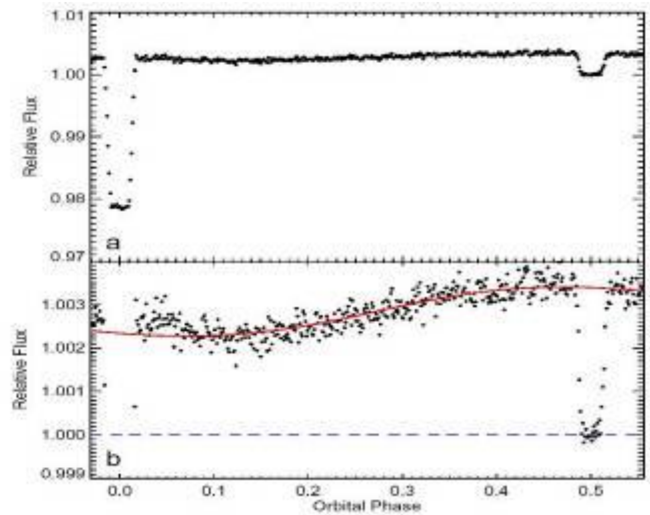
Transiting Planet Science



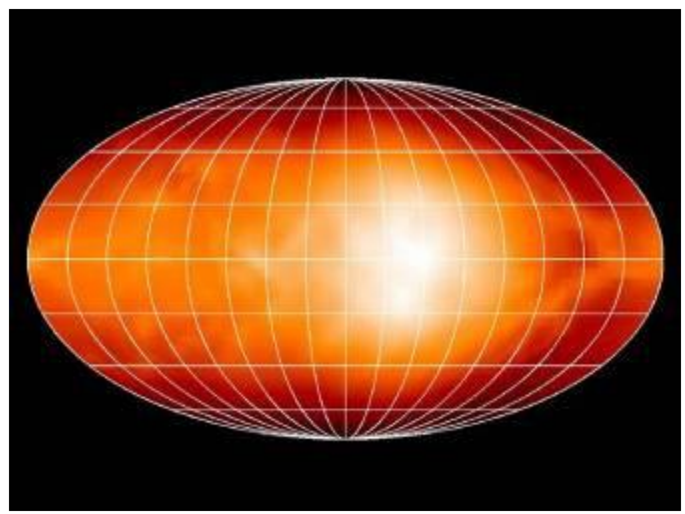
Courtesy Lori Allen

HD 189733b: First [one-dimensional] temperature map of an exoplanet

- 970K on night side; 1210K on day side
- “warm spot” 30 degrees E of high-noon point.
- High “easterly” winds, 6000 mph, carry heat around planet
- Precise Spitzer observations indicate elliptical orbit => unseen planet, could be as small as Earth?



Data – flux at 8um over more than half an orbit



Model: Assumes tidal locking of planet to star and extrapolates in latitude.

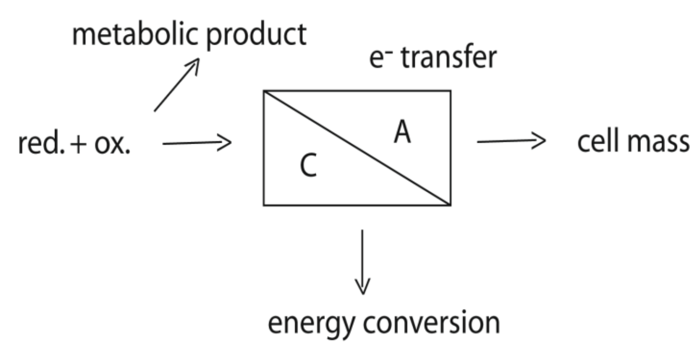
Michael Werner, “Spitzer Space Telescope”, William H. Pickering Lecture, AIAA Space 2007.

Search for Life

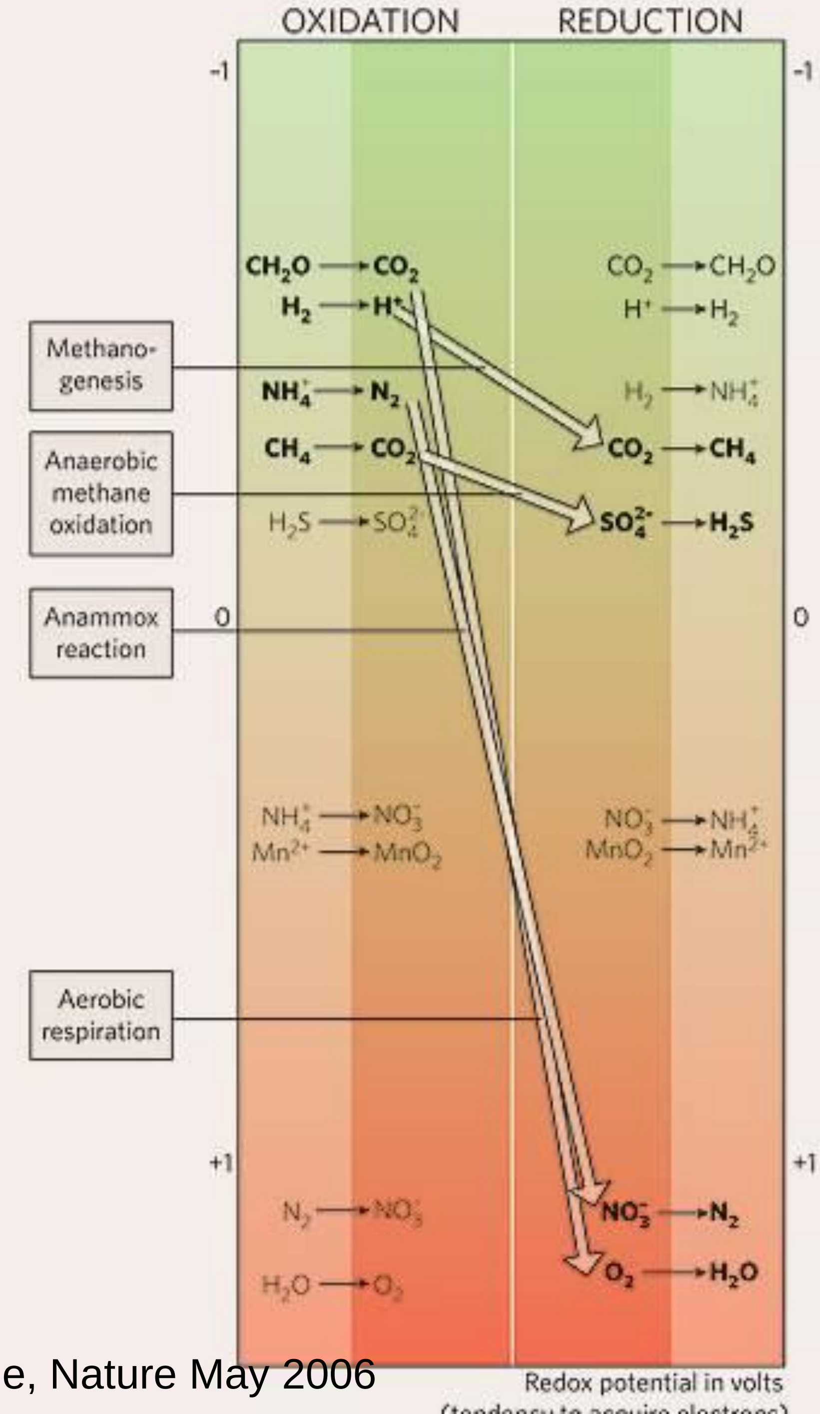
~~What is life?~~

What does life do?

Life Metabolizes



Sara Seager (2006)



Lane, Nature May 2006

All Earth life uses chemical energy generated from redox reactions

Life takes advantage of these spontaneous reactions that are kinetically inhibited

Diversity of metabolisms rivals diversity of exoplanets

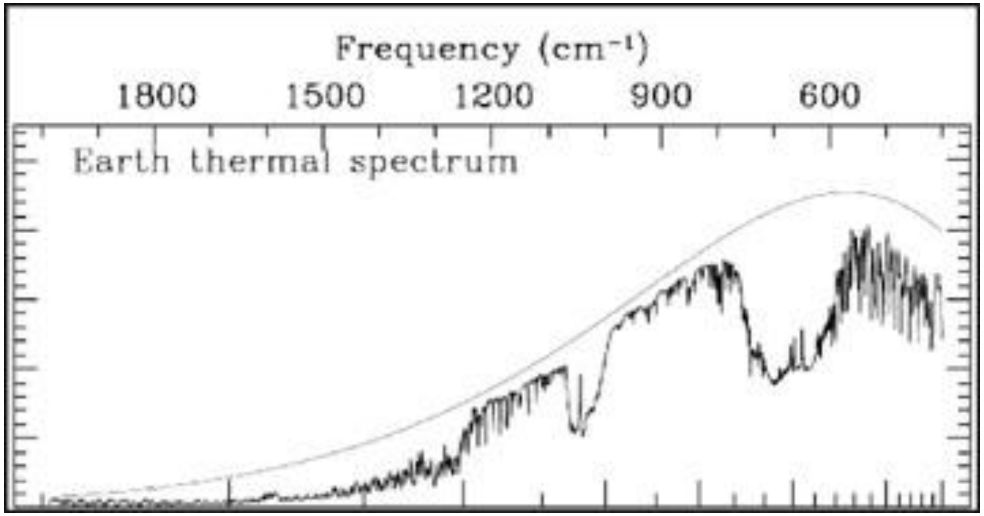
Sara Seager (2006)

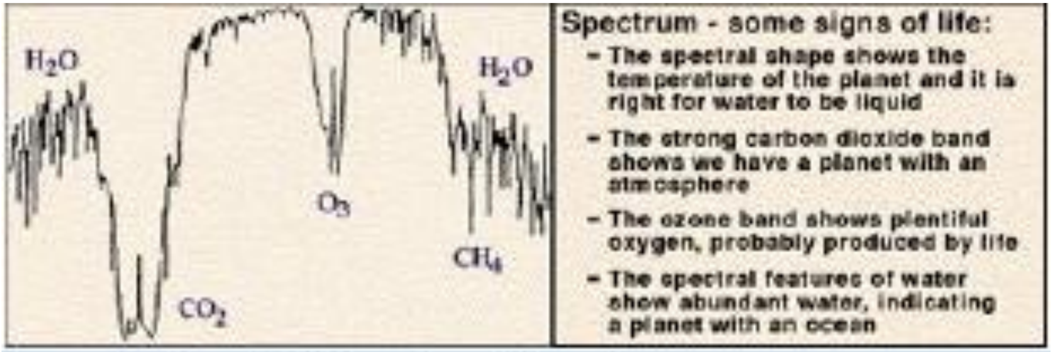
Bio Markers

Spectroscopic Indicators of Life

Absorption Lines

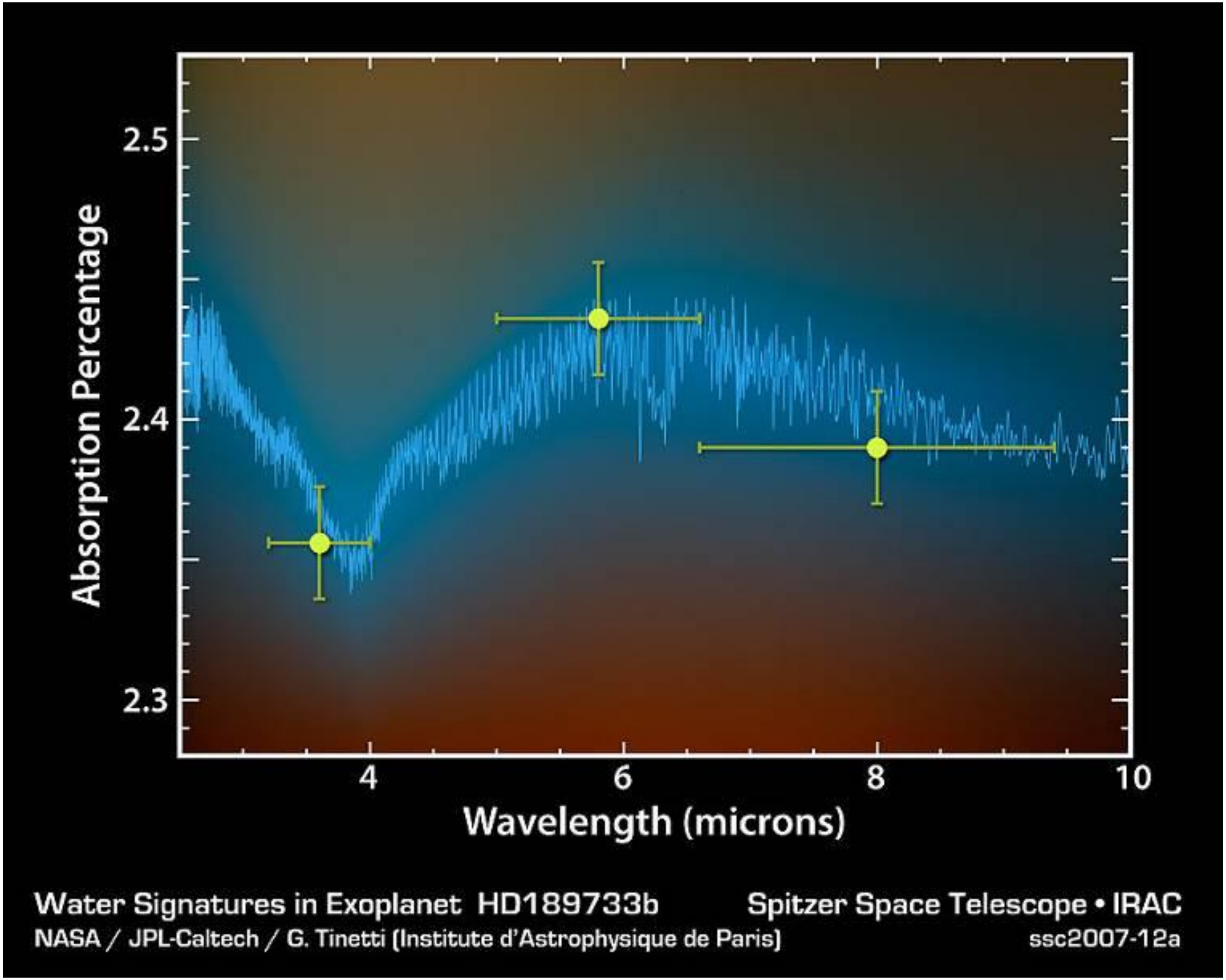
- CO2
- Ozone
- Water
- “Red” Edge





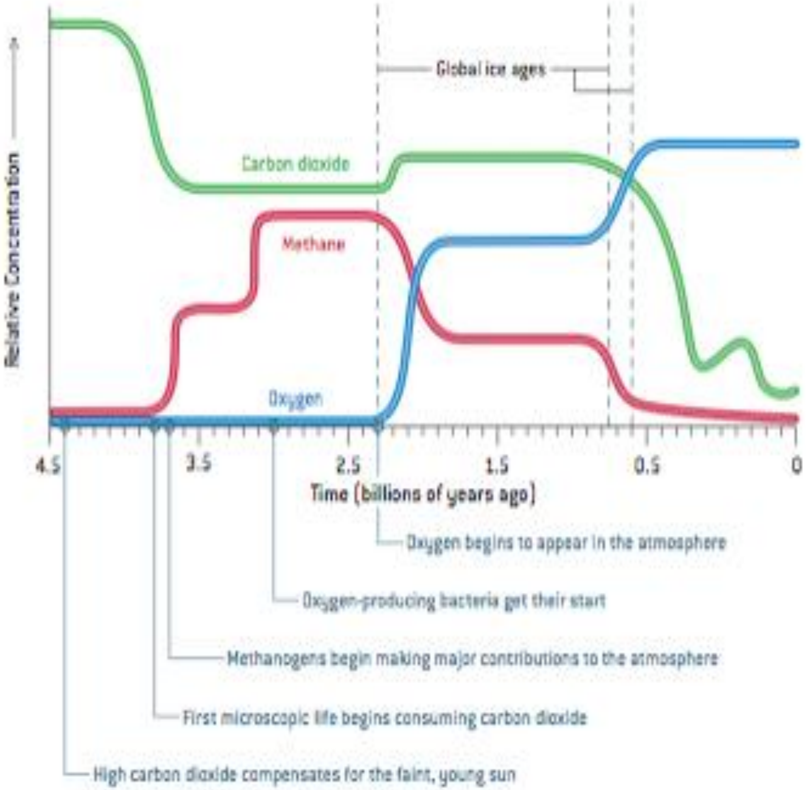
Example signs of life from chemical spectra.
Credit: NASA JPL

Is there water in an Exoplanet?

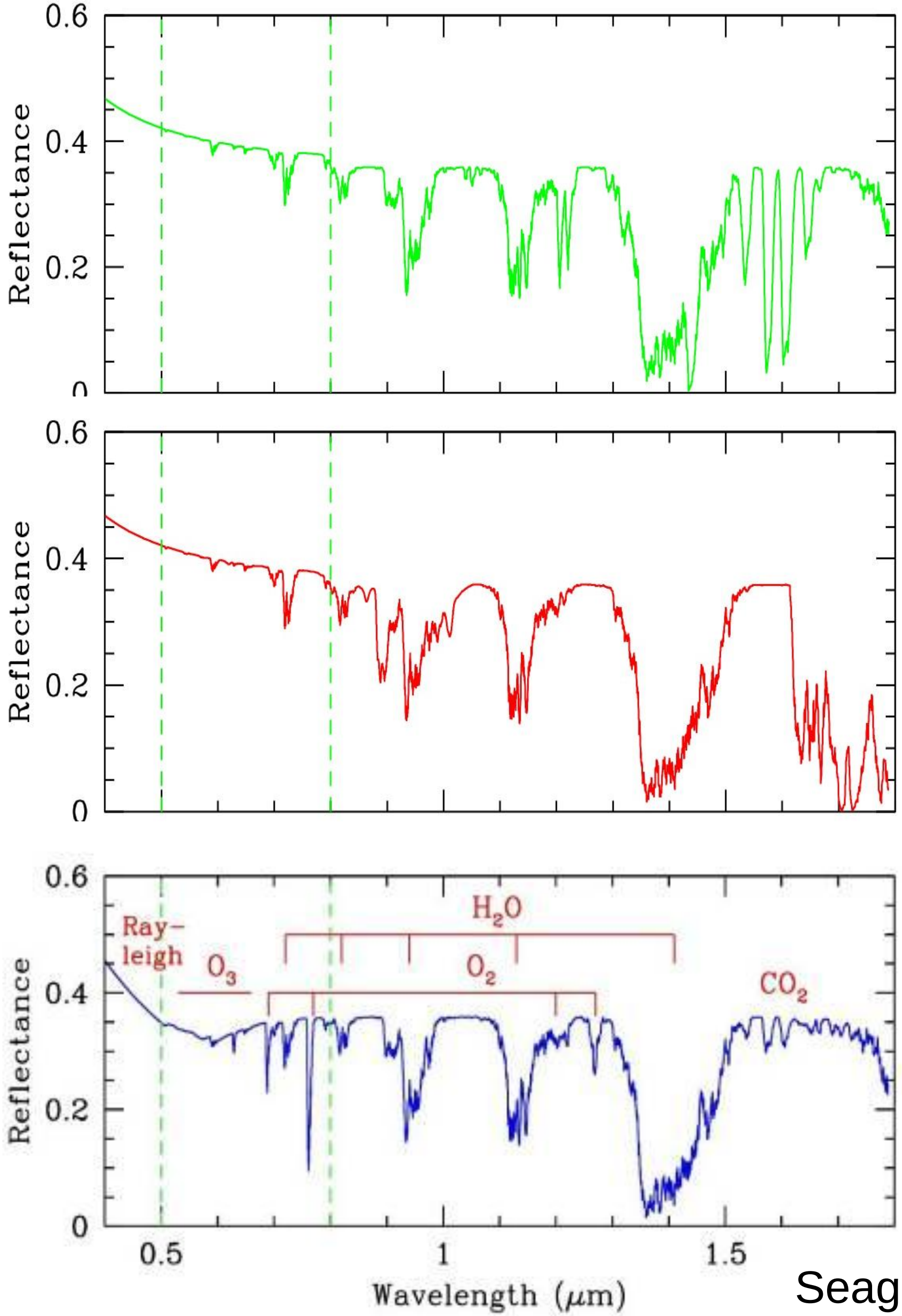


Michael Werner, "Spitzer Space Telescope", William H. Pickering Lecture, AIAA Space 2007.

Earth Through Time



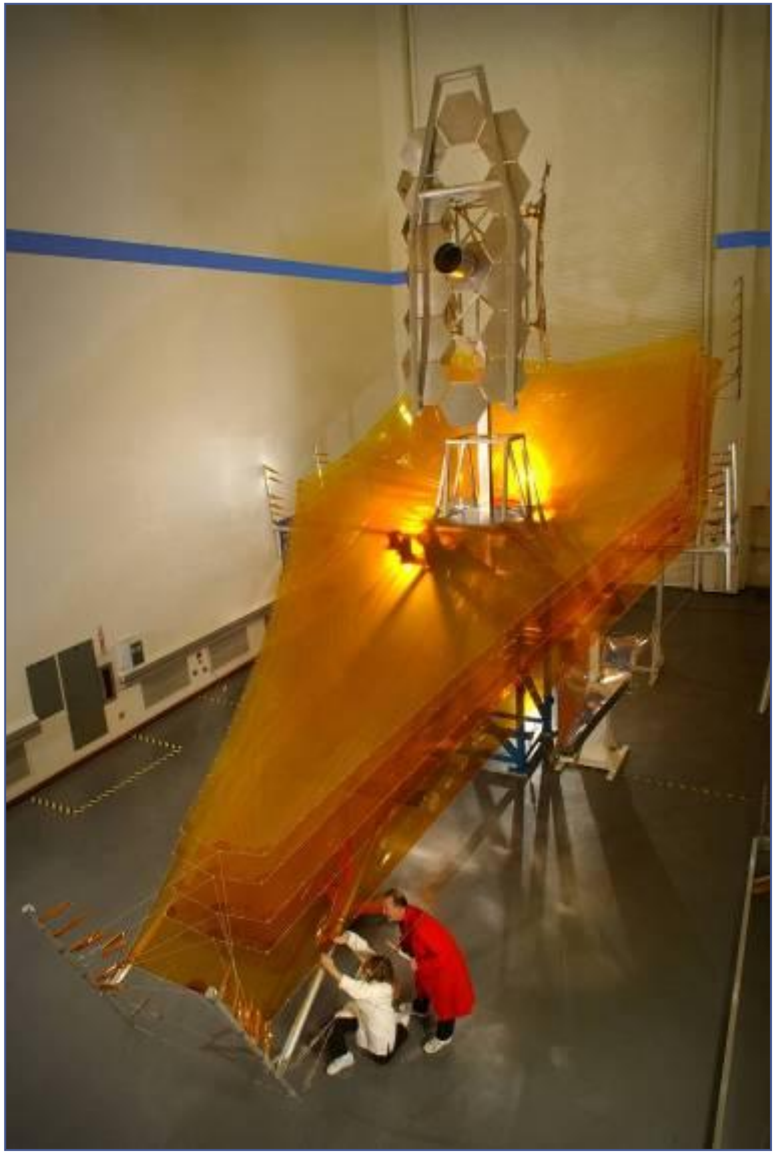
Kasting Sci. Am. 2004
See Kaltenegger et al. 2006
Earth from the Moon



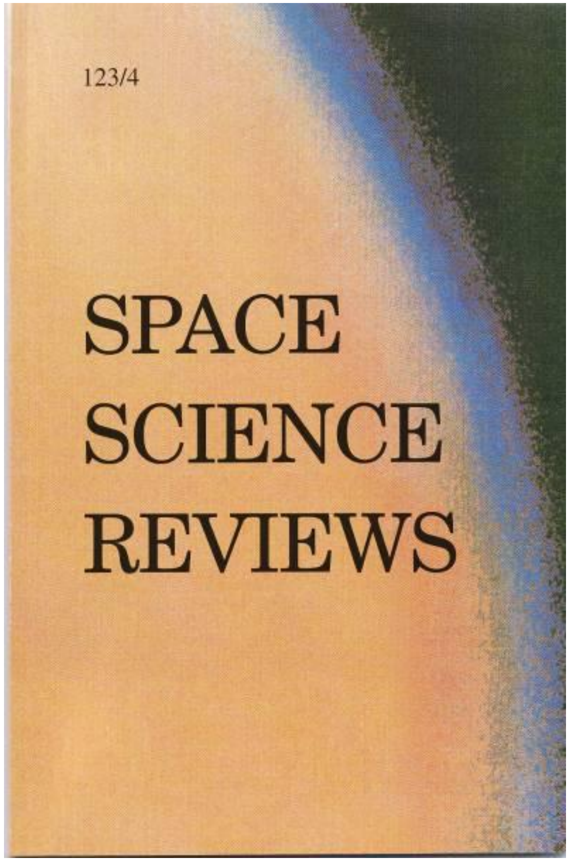
Seager

Countdown to Launch

Planned for 2014 Launch



Learn more at: www.jwst.nasa.gov



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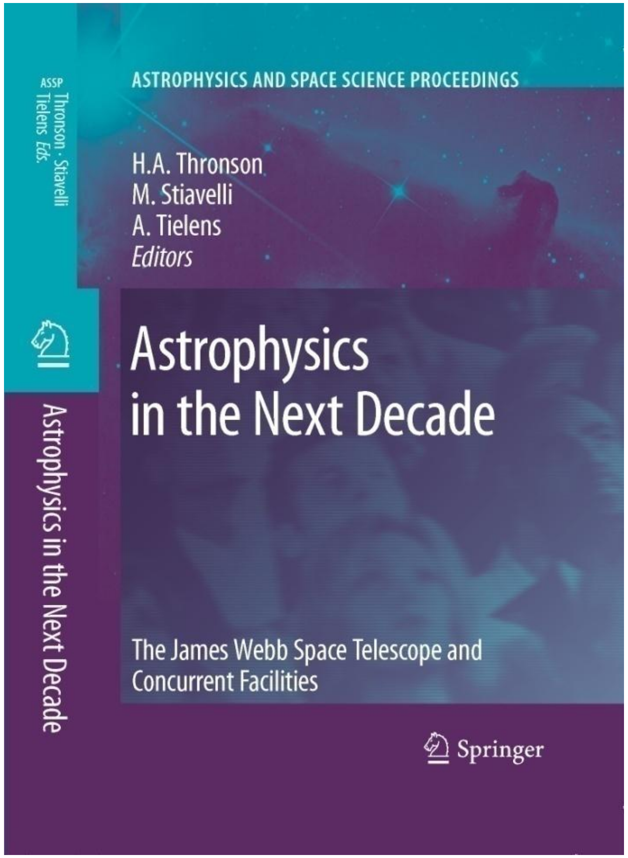
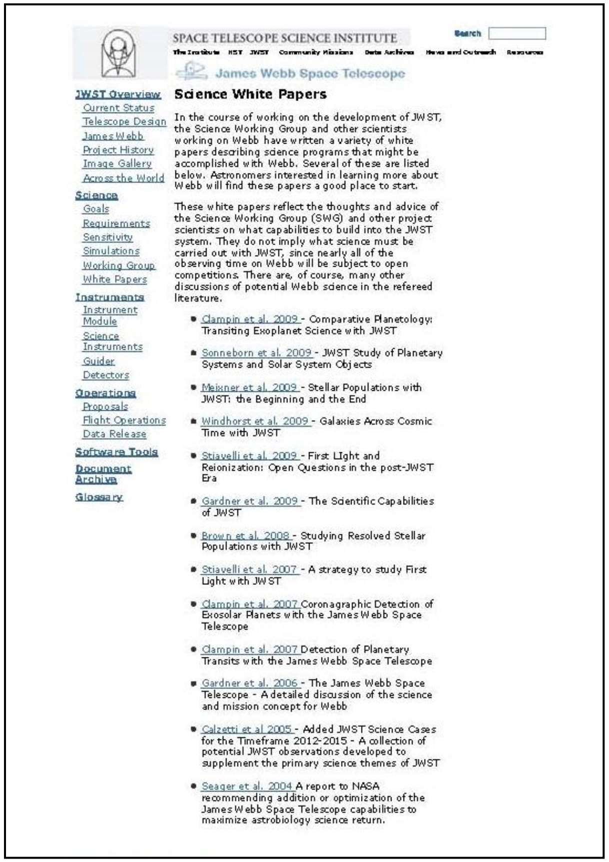
jwst.gsfc.nasa.gov

New



Available Now

New



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James Webb Space Telescope

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Glossary

Science White Papers

In the course of working on the development of JWST, the Science Working Group and other scientists working on Webb have written a variety of white papers describing science programs that might be accomplished with Webb. Several of these are listed below. Astronomers interested in learning more about Webb will find these papers a good place to start.

These white papers reflect the thoughts and advice of the Science Working Group (SWG) and other project scientists on what capabilities to build into the JWST system. They do not imply what science must be carried out with JWST, since nearly all of the observing time on Webb will be subject to open competitions. There are, of course, many other discussions of potential Webb science in the refereed literature.

- Clampin et al. 2009 - Comparative Planetology: Transiting Exoplanet Science with JWST
- Sonneborn et al. 2009 - JWST Study of Planetary Systems and Solar System Objects
- Meixner et al. 2009 - Stellar Populations with JWST: the Beginning and the End
- Windhorst et al. 2009 - Galaxies Across Cosmic Time with JWST
- Stiavelli et al. 2009 - First LIght and Reionization: Open Questions in the post-JWST Era
- Gardner et al. 2009 - The Scientific Capabilities of JWST
- Brown et al. 2008 - Studying Resolved Stellar Populations with JWST
- Stiavelli et al. 2007 - A strategy to study First Light with JWST
- Clampin et al. 2007 Coronagraphic Detection of Exosolar Planets with the James Webb Space Telescope
- Clampin et al. 2007 Detection of Planetary Transits with the James Webb Space Telescope
- Gardner et al. 2006 - The James Webb Space Telescope - A detailed discussion of the science and mission concept for Webb
- Calzetti et al 2005 - Added JWST Science Cases for the Timeframe 2012-2015 - A collection of potential JWST observations developed to supplement the primary science themes of JWST
- Seager et al. 2004 A report to NASA recommending addition or optimization of the James Webb Space Telescope capabilities to maximize astrobiology science return.

www.stsci.edu/jwst/science/whitepapers/

Any Questions?